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FATIGUE AND FRACTURE OF TITANIUM ALUMINIDES

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Titanium aluminide composites hold great promise for application in the later stages of advanced compressor systems. This conclusion is based on the assumption that Ti_3Al composites can achieve the fatigue strength levels projected from data for the SiC/Ti 6Al-4V composite system yet remain stable to 650°C or higher temperatures. In the limited results to date, Ti_3Al composite specimens have exhibited a minimum of fiber/matrix interaction, good strength and stiffness, and significantly better fatigue strength than monolithic Ti_3Al. The good fatigue strength and high stiffness are essential for application to the high temperature compressor spacers in the minimum-weight rotor configuration being developed.

The key material design parameters for titanium aluminides and titanium aluminide composites must be identified and understood. These parameters include the fatigue and fracture behavior (crack initiation and propagation as a function of temperature, frequency, size, and stress ratio), the near threshold stress intensity crack growth rates, and the thermomechanical fatigue behavior. The interaction between crack initiation and propagation

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19) with the low ductility of titanium aluminide at room temperature is of particular importance. Heat treatment and/or mechanical working may be used to improve the ductility characteristics and thereby modify the fatigue behavior. A study of the resulting fracture surfaces could provide valuable insight for development of optimum processing for these materials.

The specific objectives of this program were to characterize and understand the mechanical behavior of titanium aluminide metal matrix composites. This investigation was preceded by an SCS-6/Ti_3Al composite development task to ensure high quality composite materials for evaluation and testing.

FOREWORD

This interim technical report is submitted in accordance with the requirement of Air Force Contract F33615-85-C-5111 CDRL Sequence Number 5 and represents Volume II of the final report covering the period 1 July 1985 through 31 July 1989. The program was conducted under the cognizance of Ms. Monica Stucke at the Materials Laboratory, Wright Research and Development Center, Wright-Patterson Air Force Base, Ohio.

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I. OBJECTIVE

The objective of Phase II of the Fatigue and Fracture of Titanium Aluminides contract was to gain an understanding of the fatigue and fracture behavior of the SiC/Ti_3Al composite system for potential application in advanced turbine engine components such as those required to meet Integrated High Performance Turbine Engine Technologies (IHPTET) goals. To achieve this objective, the mechanisms of fatigue damage and modes of failure were examined, and analytical models of fatigue life prediction used to describe monolithic materials were evaluated for their applicability to this composite system. Before an analysis of the mechanical behavior of this composite could be performed, it was essential to develop the fabrication process to manufacture consistently high quality SiC/Ti_3Al MMC. This requirement necessitated process optimization and characterization of alpha-2 titanium aluminide foil, silicon carbide fiber, and the composite system itself.

II. SUMMARY

Volume II of the final report of Phase II of the Fatigue and Fracture of Titanium Aluminides contract is a discussion of the testing and analysis of SCS-6 (SiC)/Ti_3Al (Ti-24Al-11Nb) composite conducted in Tasks II through VI. A summary and discussion of the composite optimization performed in Task I is contained in Volume I of the final report.

The Task VI program expansion testing was completed prior to that for Tasks II, III, or IV, and was performed at higher temperatures than were planned in the base program. The Task VI test matrix included tensile and creep tests to 871°C, low and high cycle fatigue at 760°C, and out-of-phase thermal mechanical fatigue from 316 to 760°C. Alternate fiber configurations, $[0\text{ deg}/90\text{ deg}]_s$ and $[0\text{ deg}/\pm45\text{ deg}/90\text{ deg}]_s$, were tested as well as an alternative Ti_3Al matrix alloy, Ti-25Al-10Nb-3V-1Mo. Comparison of the properties of the cross plied lay-ups with the unidirectional composite indicated that composite tensile strength is directly proportional to the percentage of fibers oriented parallel to the load axis and that the matrix strain-life behavior controls the strain-life response of the composite. The Ti-25Al-10Nb-3V-1Mo matrix composite demonstrated higher longitudinal strength than the Ti-24Al-11Nb material, but extremely poor transverse strength and ductility. The composite showed no frequency dependence of fatigue behavior at 760°C and thermal mechanical fatigue life depended on the strain range experienced by the matrix during an out-of-phase cycle.

The SCS-6/Ti-24Al-11Nb composite fabricated for the Tasks II, III, and IV testing showed improved longitudinal and transverse strength to that tested in Task VI. This is attributed to improvements in the fabrication process. The composite achieved between 93 and 100% of the calculated rule-of-mixtures strength.

In Task II, 120 low cycle and high cycle fatigue tests were performed to determine the effect of temperature, orientation, notches, R-ratio, and frequency on the isothermal fatigue behavior of this composite system. Fatigue initiation and crack growth could only be identified at elevated temperature on the fracture surfaces. Initiations occurred at the surface of the gage in longitudinal specimens and at the fiber-matrix interface in transverse specimens. Longitudinal specimens showed equivalent fatigue life at 26 and 316°C, but reduced life at 649°C. Transverse and 45-deg oriented specimens had a higher fatigue limit at elevated temperature than at room temperature. The 649°C fatigue life of longitudinal and 45 deg specimens was equivalent. Longitudinal composite demonstrated a notch sensitivity equivalent to a cast monolithic material, but transverse tests showed no notch sensitivity. Room temperature low cycle fatigue (LCF) and high cycle fatigue (HCF) were correlated by maximum strain and independent of the applied strain range. At elevated temperatures the R-ratio dependence was more typical of that of a monolithic material and did not show a correlation with maximum strain. No frequency dependence was demonstrated at any orientation or temperature to 649°C.

The fatigue crack growth behavior and its dependence on temperature orientation, R-ratio, and frequency were evaluated in Task III. Twenty-four tests, duplicates at each condition, were performed in which crack length was measured by potential drop. The crack propagation rates of these tests were plotted as a function of stress intensity range and appeared to be modeled well by linear

elastic fracture mechanics. Longitudinal specimens demonstrated marked resistance to crack propagation at room temperature, but predictable behavior at elevated temperatures. Transverse specimens showed the lowest crack growth rate at 316 deg and equivalent crack growth rates at 26 and 649°C. Over the entire range of temperatures tested, the crack growth rate in transverse material was at least five orders of magnitude higher than that in longitudinal composite. The room temperature longitudinal crack growth data measured at R of 0.1 and 0.5 correlated on maximum stress intensity. At 649°C the higher R-ratio produced more rapid crack propagation, but no correlation similar to that at 26°C. An order-of-magnitude increase in the crack growth rate resulted from a frequency drop from 2 cpm to 0.2 cpm in longitudinal material.

The effects of phasing, temperature range, and R-ratio on thermal mechanical fatigue behavior were determined in Task IV. Both in-phase and out-of phase TMF specimens showed surface initiations similar to that for isothermal LCF. The oxidation and cracking was much less severe in those specimens cycled to 649°C than those cycled to 760°C in Task VI. Out-of-phase cycling of temperature and applied strain is a more severe cycle than in-phase cycling, and an increase in the temperature range has a negative effect on the out-of-phase fatigue limit and a positive one on that for in-phase tests. Out-of-phase TMF life can be correlated with isothermal fatigue life by total matrix strain. In-phase TMF shows a higher fatigue limit than isothermal LCF at the maximum temperature. High R-ratio, in-phase tests demonstrated fatigue only over a very narrow band of strain ranges. Failure at higher ranges occurred due to overload.

III. INTRODUCTION

3.1 BACKGROUND

The Integrated High Performance Turbine Engine Technology (IHPTET) initiative has been formed by the United States Air Force (USAF) to identify the advanced fighter engine configurations and concepts of the future. The basic IHPTET goals are to identify single- and dual-rotor engine concepts that have a thrust-to-weight ratio at twice the current levels and to demonstrate the required material/structural and component aerodynamic technologies on a timely basis for validation in the advanced turbine engine gas generator (ATEGG) and joint technology demonstrator engine (JTDE) programs. This new initiative emphasizes the development of low density, high temperature, and high strength materials for IHPTET applications to achieve the aggressive thrust-to-weight goals.

Monolithic Ti_3Al, and to a greater extent Ti_3Al reinforced with SiC fibers, provides the improved strength, density, and high temperature capability needed to produce advanced rotating compressor structures. These materials are critical for the IHPTET goals to be realized. However, before titanium aluminides can be safely implemented into man-rated components, it is essential that the fatigue and fracture characteristics of these materials are characterized and understood. The low ductility exhibited in this alloy system at room temperature and the concurrent effect of fatigue represents an unknown that must be investigated before this technology can be brought to maturity. This program represents a major step in the development of a technology base required to make the IHPTET program goals a reality.

3.2 PROGRAM SCOPE

The Phase II program effort was broken down into six tasks. These tasks are summarized as follows.

3.2.1 Task I. Composite Process Optimization

The efforts in Task I are divided into the following four major subtasks:

- o titanium aluminide foil development and manufacture
- o SCS-6 fiber production and characterization
- o SCS-6/Ti_3Al composite process development and optimization
- o SCS-6/Ti_3Al composite test panel fabrication

TIMET has employed a pack rolling practice to produce 0.150-0.200 mm Ti_3Al foil.

Textron-Specialty Materials Division has produced and characterized the SCS-6 fiber chosen for use in this program. A sufficient quantity of SCS-6 fiber to meet the needs of the program was produced at one time using standard processing procedures established for high quality fiber. A statistical definition of fiber strength has been established and only fiber from this lot was used in composite fabrication for Tasks II through IV of this program.

The SCS-6/Ti-24Al-11Nb (atomic percent) composite manufacturing process was developed by Textron-MMTC (formerly Ex-Cell-O), Textron-SMD (formerly AVCO), and Allison. In this subtask, Allison subcontracted with the two divisions of Textron to perform the bonding and optimization studies required to produce a high quality composite for testing and evaluation in Tasks II through V. Both subcontractors optimized composite processing, volume fraction fiber, and thermal treatments in complementing programs based on tensile properties. Following these efforts, Allison selected the best composite manufacturer to produce a sufficient quantity of SCS-6/Ti_3Al for testing in the remaining tasks. This approach minimized risk while maximizing technical expertise in composite manufacturing.

3.2.2 Task II. Fatigue Crack Initiation

In Task II, a program to investigate the effects of fiber orientation, temperature, frequency, R-ratio, and notches on the cycles to fatigue crack initiation and failure was conducted.

3.2.3 Task III. Fatigue Crack Growth

The Task III effort included a study of the effects of frequency, temperature, R-ratio, and fiber orientation on the fatigue crack growth behavior of the composite.

3.2.4 Task IV. Thermal Mechanical Fatigue

In Task IV, the effects of thermal mechanical fatigue on composite life were investigated. The internal stresses and strains, which develop in the composite as a result of thermal expansion mismatch, influence the fatigue behavior of the composite. The effects of both in-phase and out-of-phase thermal cycling were determined.

3.2.5 Task V. Fractographic Analysis

Task V involved fractographic analysis of failed specimens from Tasks I through IV to determine the failure mechanisms in the composite system. The knowledge gained in this task contributed to the understanding of the mechanisms of fatigue and fracture in this composite system.

3.2.6 Task VI. Program Expansion

Task VI was an extension of the testing and analysis in previous tasks. In Task VI additional testing was performed to evaluate SCS-6/Ti_3Al behavior at higher temperatures (up to 871°C), using both unidirectional and cross plied MMC and the Ti-25Al-10Nb-3V-1Mo (atomic percent) matrix.

IV. DISCUSSION

Mechanical tests performed in this program included tensile, creep, fatigue, fatigue crack growth, and thermal mechanical fatigue. The SCS-6/Ti_3Al material tested was produced in two lots. The first lot of 13 panels, manufactured for the Task VI program expansion, was consolidated using SCS-6 fiber mat woven with Ti-6Al-4V ribbon as cross weave material. The configuration of those panels is given in Table 1. The second lot of 56, unidirectionally reinforced, eight-ply SCS-6/Ti-24Al-11Nb panels was made with a molybdenum ribbon cross weave. The improvement in properties, specifically tensile properties, of the second lot of composite may be attributed to this improvement in cross weave composition. Throughout the following discussion, the mechanical behavior of both lots of composite will be presented together for evaluation and comparison.

4.1 TENSILE BEHAVIOR

Tensile tests were performed by Materials Behavior Research Corporation, Loveland, Ohio. Tensile specimens were manufactured according to Figure 1. The gages were diamond ground and longitudinally polished. Specimens were friction gripped and heated by induction. Strain was measured to failure in all tests using extensometers with a 1.27 cm gage length.

4.1.1 SCS-6/Ti-24Al-11Nb Tensile Properties

Thirty-two tensile tests were performed on SCS-6/Ti-24Al-11Nb composites manufactured for the Task VI program expansion: twelve on longitudinally oriented specimens, twelve on transverse specimens, four on $[0\ deg/90\ deg]_s$ cross-ply, and four on $[0\ deg/\pm45\ deg/90\ deg]_s$ cross-ply specimens. For the unidirectionally reinforced specimens, triplicate tests were run at each of four temperatures: 25, 649, 760, and 871°C. Duplicate tests of each cross-ply configuration were performed at 26°C and 760°C. Table 2 lists these tensile results.

Table 1.
Composite panels fabricated for add-on testing.

Panel No.	Size	Fiber mat	Matrix	Configuration --deg
A15	15 cm x 30.5 cm x 8 ply	Woven	Ti-24Al-11Nb	0
A16	15 cm x 30.5 cm x 8 ply	Woven	Ti-24Al-11Nb	0
A24	15 cm x 15 cm x 8 ply	Woven	Ti-24Al-11Nb	0
A25	15 cm x 15 cm x 8 ply	Woven	Ti-24Al-11Nb	0
A26	15 cm x 15 cm x 8 ply	Woven	Ti-24Al-11Nb	0
A27	15 cm x 15 cm x 8 ply	Woven	Ti-24Al-11Nb	0
A28	15 cm x 15 cm x 8 ply	Woven	Ti-25Al-10Nb-3V-1Mo	0
A30	15 cm x 15 cm x 8 ply	Woven	Ti-25Al-10Nb-3V-1Mo	0
A31	15 cm x 15 cm x 8 ply	Woven	Ti-25Al-10Nb-3V-1Mo	0
A32	15 cm x 15 cm x 8 ply	Woven	Ti-24Al-11Nb	0/90
A33	15 cm x 15 cm x 8 ply	Woven	Ti-24Al-11Nb	0/90
A35	15 cm x 15 cm x 8 ply	Woven	Ti-24Al-11Nb	0/+45/-45/90
A45	15 cm x 15 cm x 8 ply	Woven	Ti-24Al-11Nb	0/+45/-45/90

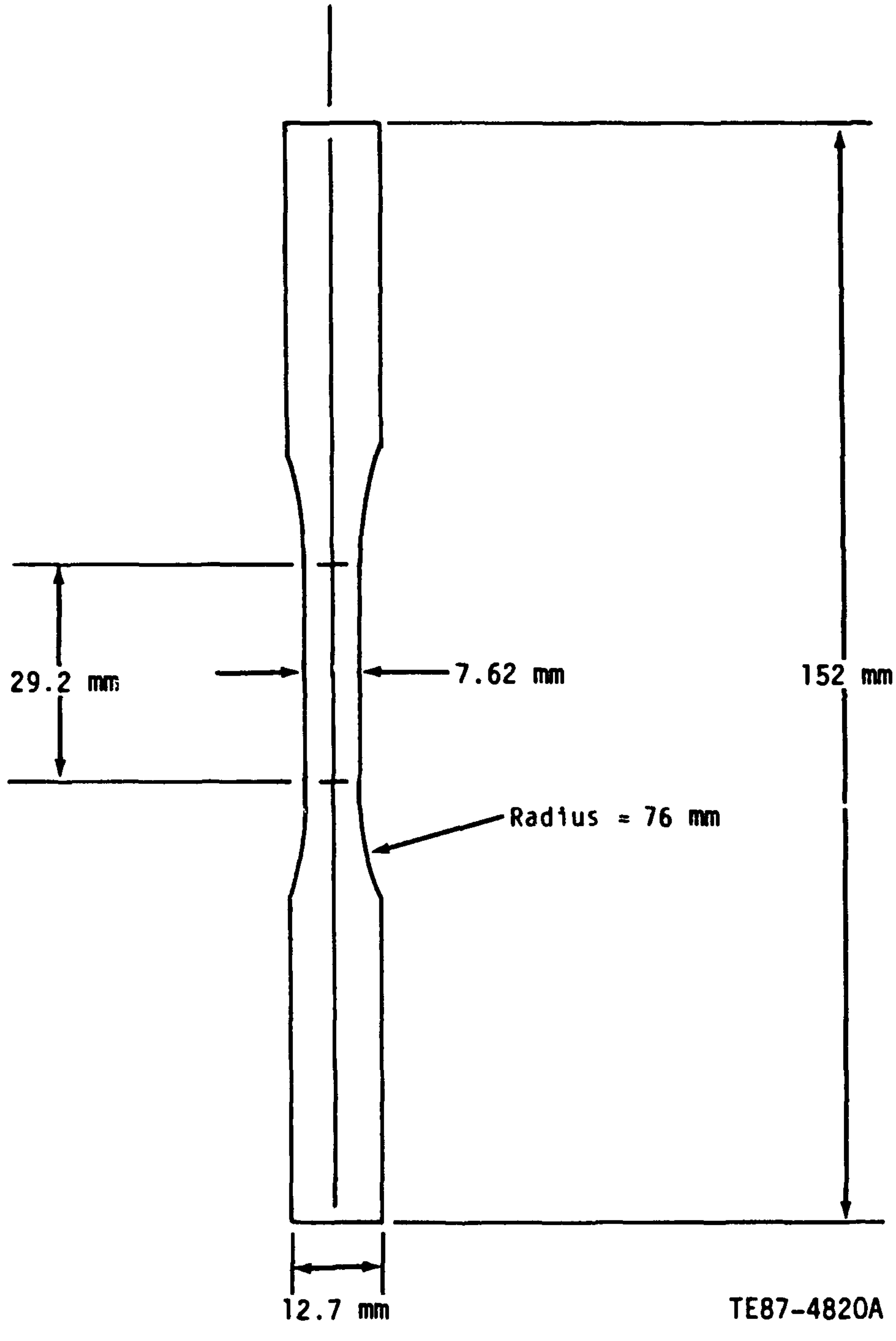


Figure 1. Test specimen for fiber reinforced composite.

Table 2.
Tensile properties of eight-ply SCS-6/Ti-24Al-11Nb composite manufactured for the Task VI program expansion.

Specimen No.	Test temperature --°C	RT moculus --GPa	TT modulus --GPa	0.02% yield strength --MPa	Ultimate tensile strength --MPa	% total strain
Longitudinal						
15L-5	25	182.0	182.0	859.8	1150.8	0.75
16L-2	25	177.2	177.2	873.6	1237.6	0.82
27L-2	25	191.0	191.0	679.8	1353.5	0.98
15L-8	649	182.7	158.6	704.7	881.8	0.575
16L-19	649	179.3	151.7	788.1	1134.2	0.84
27L-4	649	184.1	158.6	574.4	1091.5	0.79
15L-10	760	185.5	133.8	------	790.2	0.55
16L-14	760	175.8	131.0	704.0	961.2	0.75
27L-6	760	190.3	162.7	271.4	997.7	0.78
15L-2	871	201.3	153.1	608.1	757.8	0.55
16L-8	871	164.8	117.9	------	888.1	0.74
27L-8	871	173.1	128.9	775.7	912.9	0.76
Transverse						
15T-5	25	128.9	128.9	------	191.7	0.175
25T-1	25	137.2	137.2	217.2	228.9	0.200
24T-3	25	142.0	142.0	241.3	253.0	0.218
15T-1	649	91.7	45.5	73.8	121.4	0.54
24T-6	649	104.8	83.4	66.9	139.3	0.610
25T-6	649	97.2	73.1	50.3	117.9	0.665
15T-2	760	95.2	27.6	35.2	85.5	2.16
24T-5	760	128.9	77.9	51.0	99.3	1.935
24T-10	760	144.1	88.3	48.9	100.7	1.430
15T-3	871		Failed test			
24T-2	871	102.7	37.9	28.3	79.3	2.25+
24T-1	871	131.7	24.1	25.5	55.8	4.24
$[0\ deg/90\ deg]_s$						
32-6	25.5	144.8	144.8	253.7	768.8	1.05
33-8	25.5	122.0	122.0	358.5	686.1	1.12
32-2	760	136.5	92.4	239.2	585.4	0.79
33-6	760	137.9	93.0	275.1	577.1	0.75

Table 2 (cont)

Specimen No.	Test temperature --°C	RT moculus --GPa	TT modulus --GPa	0.02% yield strength --MPa	Ultimate tensile strength --MPa	% total strain
$[0\ deg/\pm45\ deg/90\ deg]_s$						
35-7	25.5	124.8	124.8	251.7	596.4	1.01
45-9	25.5	128.9	128.9	192.3	627.4	0.98
35-3	760	131.7	74.5	76.5	383.4	0.87
45-6	760	124.1	71.7	113.1	375.8	0.80

Selected panels from the 56 panels manufactured for testing in Tasks II, III, and IV were tensile tested over a range of temperatures from 26°C to 760°C. These data for both longitudinal and transverse specimens is given in Table 3.

Room temperature modulus measurements were made prior to heating on all elevated temperature tests to determine a statistically relevant scatter in modulus for this material. Figure 2 shows a plot of modulus as a function of temperature for both transverse and longitudinal specimens for both lots of composite. The longitudinal modulus averages 183.5 GPa at 25°C and falls to an average of 155 GPa at 649°C. The transverse modulus demonstrated more scatter than the longitudinal. There does not seem to be an effect of process variations on composite modulus.

There is little or no plastic strain associated with these tensile tests. In most results 0.2% yield strength could not be measured. Please note that the 0.02% yield strength is reported instead.

Figure 3 shows a comparison of the ultimate tensile strength of both longitudinal and transverse specimens in both lots of composite. The average tensile strengths of the Task VI composite measured are 83% of the calculated rule-of-mixtures strength for this composite system. (The rule-of-mixtures strength is calculated from the fiber bundle strength and the strength measured in tests of foil consolidated without fiber.) The Tasks II, III, and IV composite showed improved longitudinal strength of 96% of the rule-of-mixtures. The average room temperature strength of the early material was 1250 MPa compared with 1480 MPa for the second lots of composite. The transverse strength did not vary significantly from one lot to the other, averaging 242 MPa at room temperature and 123 MPa at 649°C.

One specimen from each of three of the Task VI panels was tested in the longitudinal orientation at each temperature. The lowest strength point at each temperature is a specimen from panel A15. This panel did not show any indications in nondestructive evaluation (NDE) that it possessed lower strength. Failure analysis of the tested specimens, shown in Figure 4, shows that there is a greater degree of fiber pullout in the panel 15 specimens than in those from panels 16 or 27. Otherwise the fractures are similar--brittle matrix

Table 3.
Tensile properties of SCS-6/Ti-24Al-11Nb.

Specimen No.	Test temperature --°C	RT modulus --GPa	TT modulus --GPa	0.02% yield strength --MPa	Ultimate tensile strength --MPa	% total strain
Traverse						
82-1	26	151	151	271	271	0.2
82-2	26	134	134	252	266	0.25
82-4	316	129	119	135	193	0.289
82-5	316	146	137	145	197	0.434
82-6	649	117	77	55	117	0.89
82-8	649	124	84	51	119	0.94
82-9	760	145	71	44	96	1.88
82-11	760	113	42	40	91	1.545
Longitudinal						
93-1	26	184	184	655	1442	1.07
93-2	26	195	195	706	1494	1.09
93-3	26	186	186	690	1495	1.085
93-4	316	172	169	729	1299	0.98
93-5	316	188	186	702	1330	0.95
93-6	538	174	154	848	1152	0.86
93-7	538	185	166	797	1185	0.868
93-8	649	186	151	683	1136	0.84
93-9	649	186	153	703	1201	0.895
93-10	649	186	155	641	1165	0.85
101-5	760	183	136	865	1055	0.805
103-5	760	192	139	924	1079	0.79

fracture with little fiber pullout at room temperature and increasing ductility and fiber matrix separation with temperature.

Elongation and reduction in area are not meaningful measurements in tests of these composites. However, because total strain is generally small (less than one percent in longitudinal specimens) extensometry is left in place throughout the test, and total strain at failure is recorded. Figure 5 shows the variation in total strain at failure as a function of temperature for longitudinal and transverse specimens of both lots. The strain in longitudinal specimens is determined by the maximum strain achievable in the SCS-6 fiber, which is

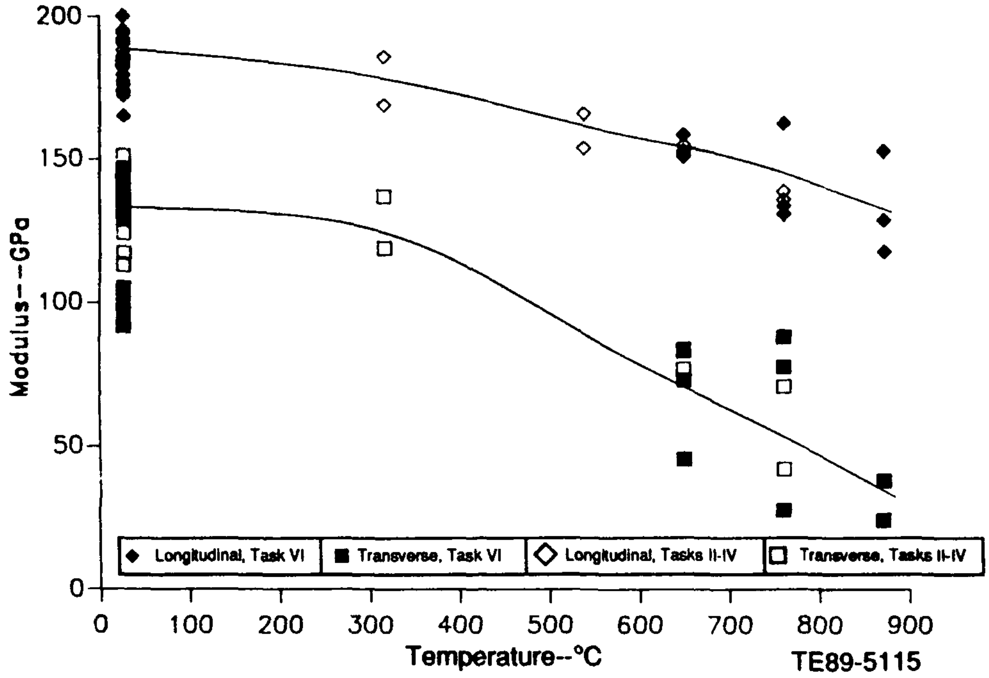


Figure 2. Tensile modulus of unidirectionally reinforced SCS-6/Ti-24Al-11Nb composite.

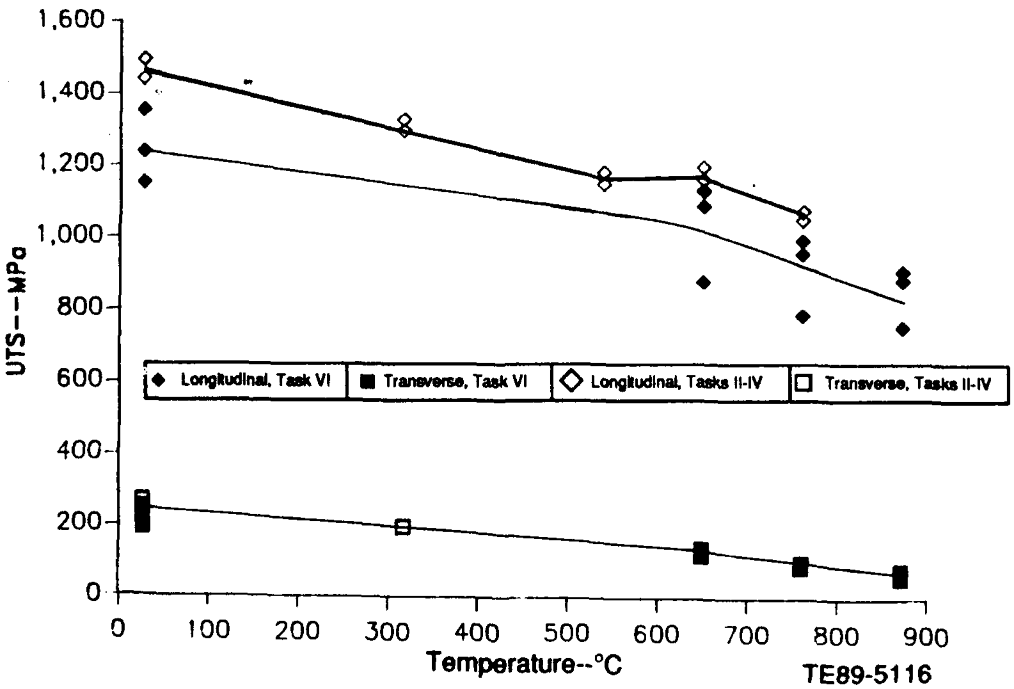
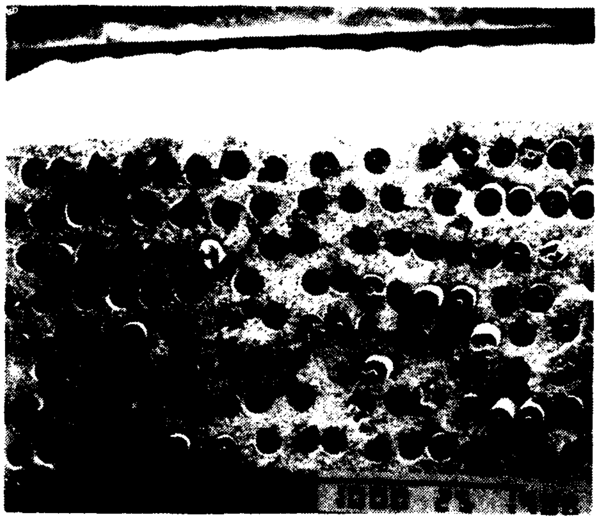
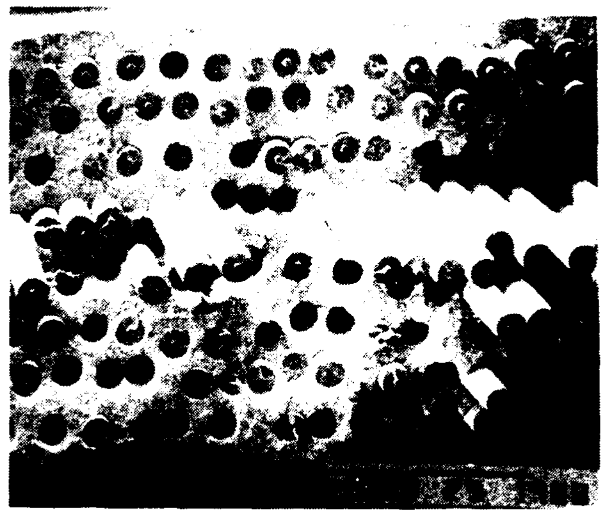


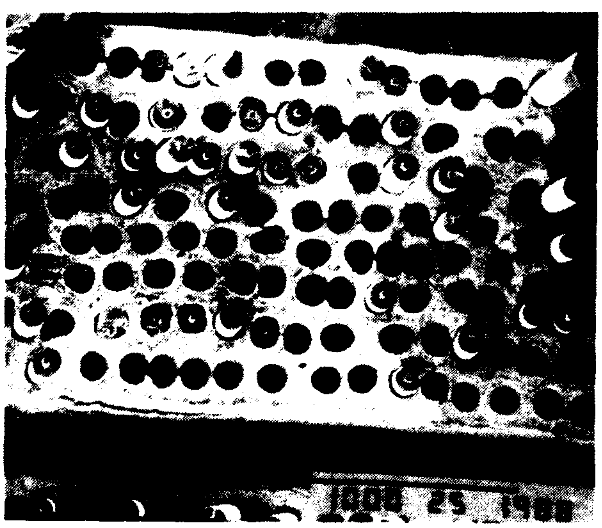
Figure 3. Ultimate tensile strength of unidirectionally reinforced SCS-6/Ti-24Al-11Nb composite.



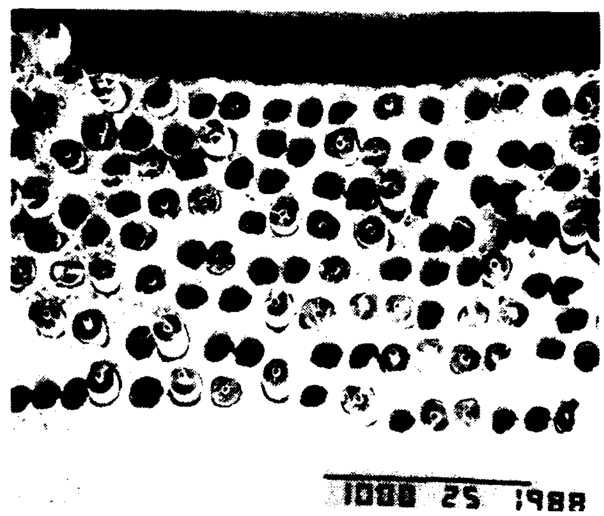
(A) 25°C 27L-2



(B) 25°C 15L-5



(C) 760°C 16L-14



(D) 760°C 15L-10

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Figure 4. Tensile fractures of longitudinal SCS-6/Ti-24Al-11Nb composite. Note the large amount of fiber pullout in specimen 15L-5 (B) compared to the higher strength specimen 27L-2 (A). At 760°C the lower strength specimen 15L-10 (D) has a rougher fracture surface than 16L-14 (C).

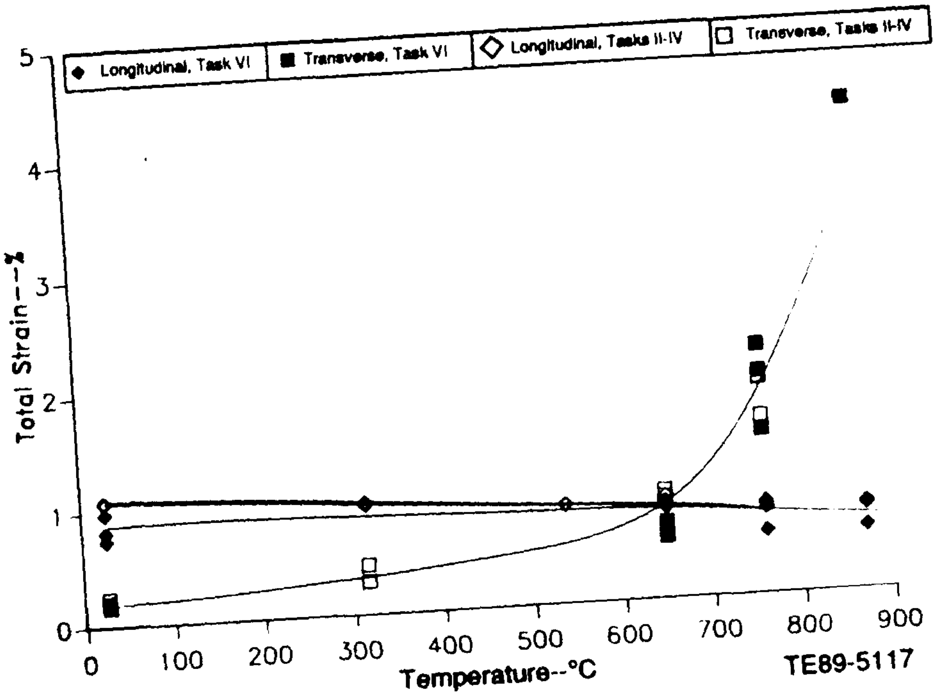

Figure 5. Total strain at failure for tensile tests of unidirectionally reinforced SCS-6/Ti-24Al-11Nb composite.

approximately 1%. The composite of the second lot showed a slight improvement in longitudinal strain at room temperature but no difference in transverse behavior.

The transverse specimens are brittle at room temperature (averaging 0.2% total strain), but at elevated temperatures their ductility increases rapidly. At 871°C the total strain in two of the three tests was unmeasurable because it exceeded the maximum travel of the extensometer.

Duplicate tests were also performed at 25°C and 760°C on two types of cross ply configurations: the [0 deg/90 deg]$_s$ and [0 deg/$\pm$45 deg/90 deg]$_s$ eight ply, symmetric lay-ups. The results from these tests are tabulated in Table 2. Figure 6 shows the tensile strength of the cross ply specimens compared with the longitudinal and transverse specimens of the unidirectionally reinforced material fabricated in the same lot. The strengths vary as predicted. The fiber strength controls the behavior of a longitudinally oriented composite in tension. Thus, the [0 deg/90 deg]$_s$ configuration is of higher strength than [0 deg/$\pm$45 deg/90 deg]$_s$ because it has a greater percentage of fibers in the longitudinal orientation.

4.1.2 SCS-6/Ti-25Al-10Nb-3V-1Mo

Of the thirteen panels fabricated for the Task VI program expansion, three panels were consolidated with unidirectionally rolled Ti-25Al-10Nb-3V-1Mo foil and SCS-6 fiber. Eight specimens in each orientation were tensile tested of the SCS-6/Ti-25Al-10Nb-3V-1Mo (atomic percent) composite. The test results are shown in Table 4 and Figures 7, 8, and 9. The longitudinal data and comparison of the longitudinal curves indicate this composite system has higher strength and modulus than and identical total ductility to the SCS-6/Ti-24Al-11Nb system in this orientation.

Table 4.
Tensile properties of unidirectional eight-ply SCS-6/Ti-25Al-10Nb-3V-1Mo (atomic percent) composite.

Specimen No.	Test temperature --°C	RT modulus --GPa	TT modulus --GPa	0.02% yield strength --MPa	Ultimate tensile strength --MPa	% total strain
Longitudinal						
30L-1	25.5	187.5	187.5	1203.2	1288.0	0.73
30L-9	25.5	190.3	190.3	964.6	1312.8	0.795
30L-3	649	191.0	171.7	1056.3	1284.5	0.82
30L-4	649	204.1	187.5	954.3	1218.3	0.705
30L-2	760	193.7	171.0	664.7	1076.3	0.72
30L-5	760	195.8	170.3	649.5	983.2	0.66
30L-6	871	190.3	150.3	699.8	911.5	0.67
30L-7	871	184.7	140.0	------	775.0	0.58
Transverse						
31T-6	25.5	92.4	92.4	------	71.0	----
28T-3	649.0	------	72.4	85.5	85.5	0.14
28T-4	649.0	Failed test				
28T-5	760.0	------	84.1	48.3	60.7	0.18
31T-3	760	95.1	Failed test			
31T-8	760	100.0	53.1	37.2	58.6	0.23
28T-6	871.0	------	53.1	42.7	57.9	0.18
31T-1	871.0	Failed test				

The transverse data illustrate a deficit in matrix ductility in this system. The transverse modulus is surprisingly low at room temperature (although Ti-25-10-3-1 has a higher monolithic modulus than Ti-24-11) as well as the strength. Both properties may be related to the extreme lack of ductility in the transverse orientation. The room temperature specimens were too brittle and weak to support an extensometer, and even at elevated temperature the total strain at failure was never greater than 0.23%. It must be noted that the consolidation conditions used in this work were optimized for the Ti-24-11 matrix. It is possible that an alternative consolidation cycle would produce a composite with the Ti-25-10-3-1 matrix improved transverse properties.

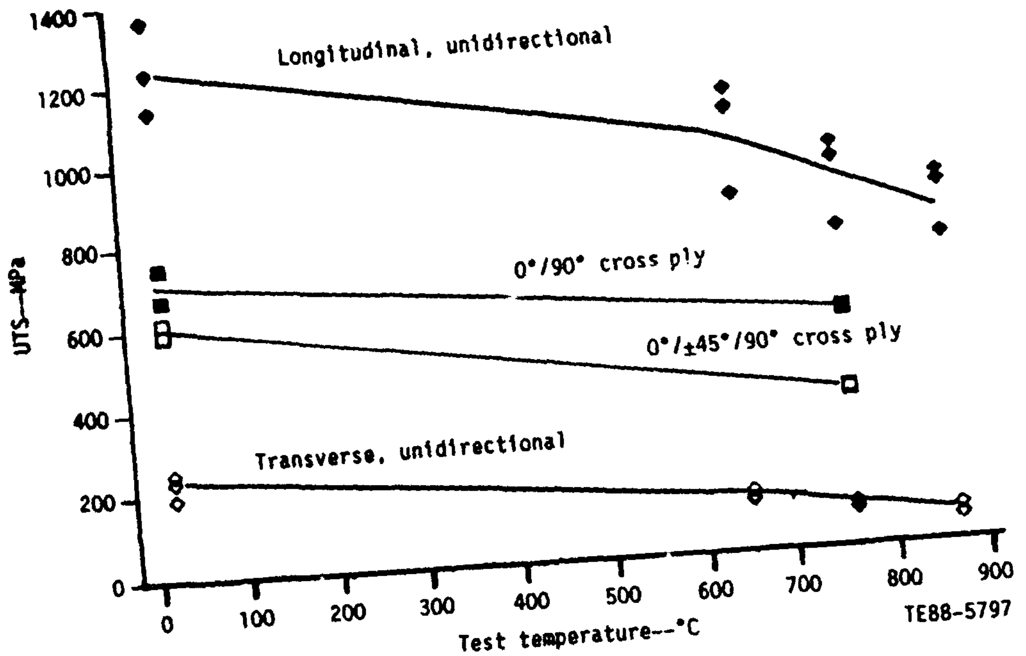

Figure 6. Ultimate tensile strength of cross ply, both [0 deg/90 deg]$_s$ and [0 deg/±45 deg/90 deg]$_s$, SCS-6/Ti-24Al-11Nb composite compared with that of the unidirectionally reinforced composite.

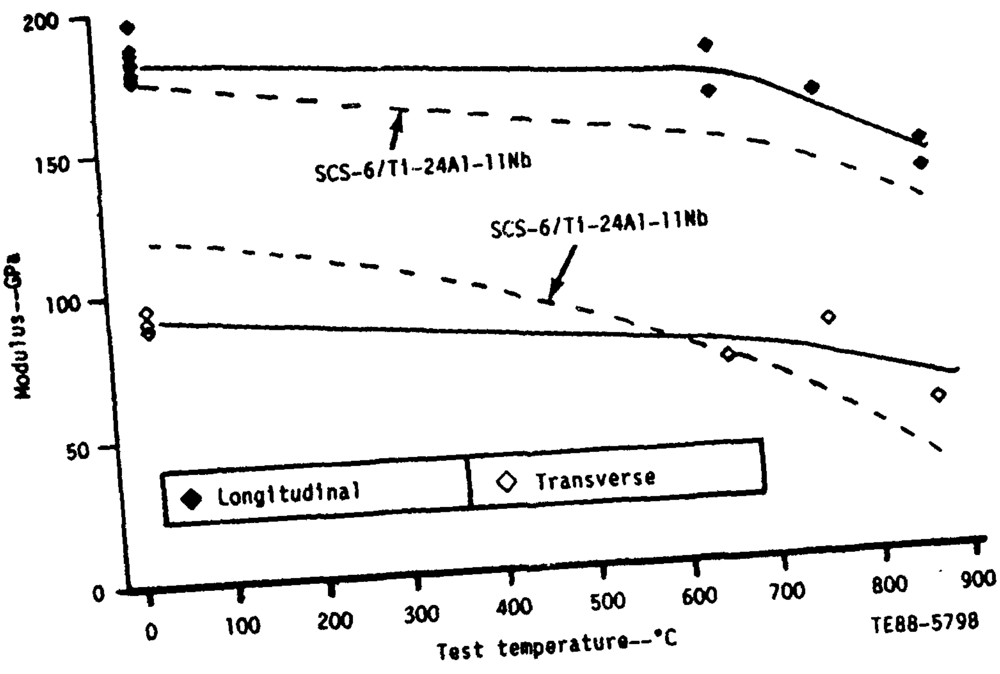

Figure 7. Modulus of SCS-6/Ti-25Al-10Nb-3V-1Mo composite compared with that of SCS-6/Ti-24Al-11Nb composite.

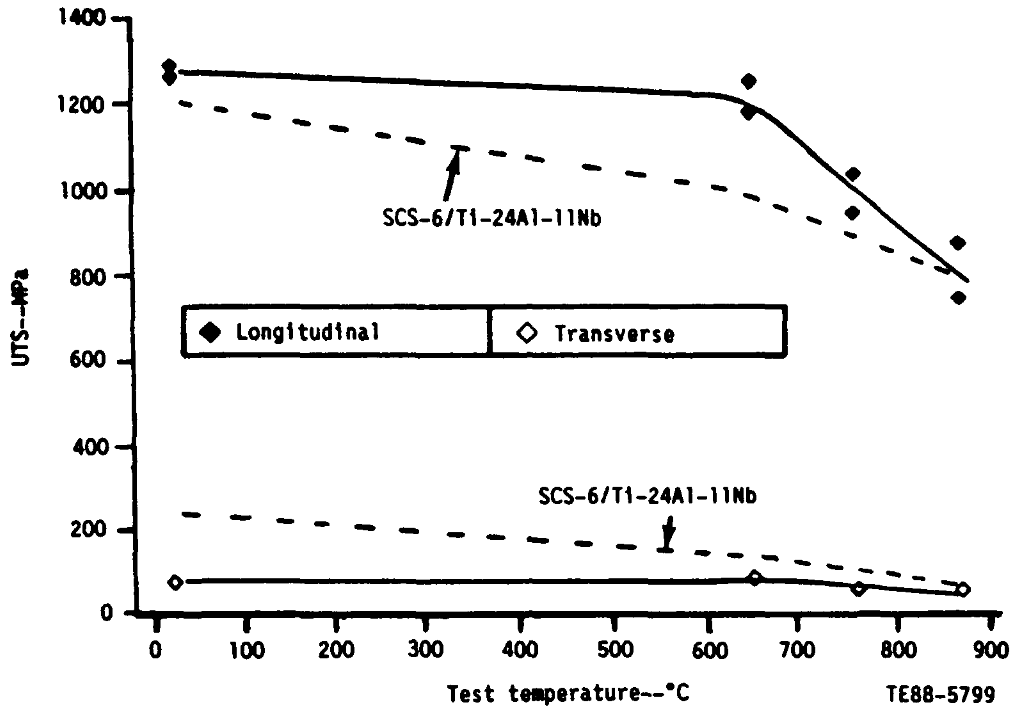

Figure 8. Ultimate tensile strength of SCS-6/Ti-25Al-10Nb-3V-1Mo composite compared with that of SCS-6/Ti-24Al-11Nb.

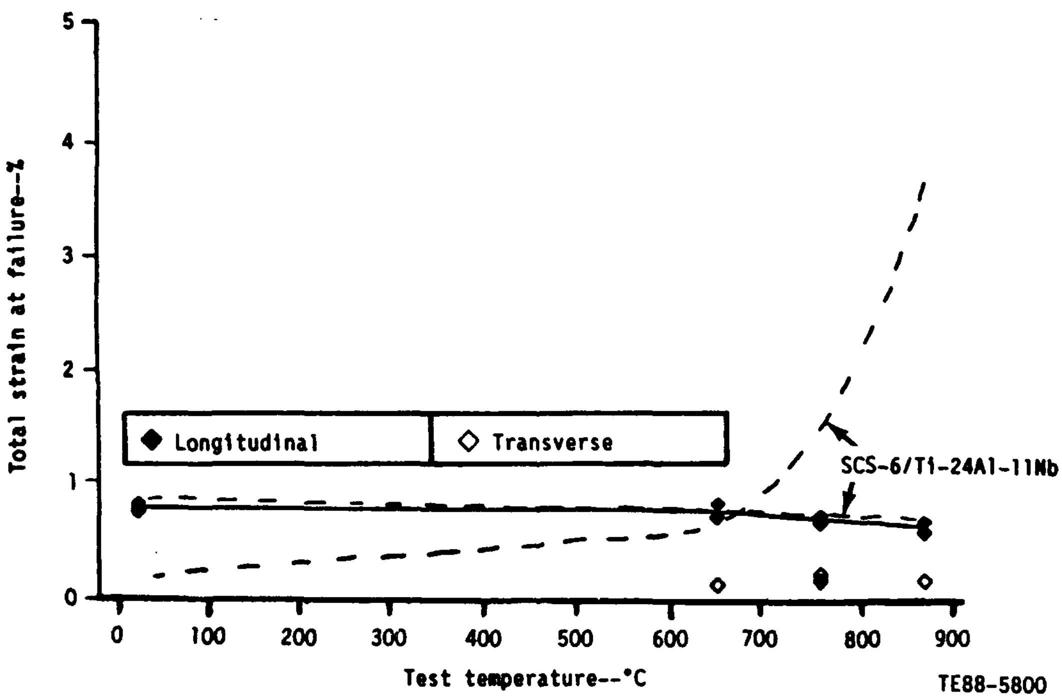

Figure 9. Total strain at failure of SCS-6/Ti-25Al-10Nb-3V-1Mo compared with that of SCS-6/Ti-24A-11Nb.

4.2 CREEP-RUPTURE BEHAVIOR

Creep testing was conducted at Metcut Research Associates, Cincinnati, Ohio. Specimens were friction gripped between metal plates bolted together. Specimens and grips were heated to temperature within a furnace. Creep strain as a function of time was monitored with extensometry. All the composite material tested in creep was manufactured for the Task VI program expansion.

4.2.1 SCS-6/Ti-24Al-11Nb

Creep rupture tests were conducted on both unidirectionally reinforced and cross ply SCS-6/Ti-24Al-11Nb composite. Table 5 lists the results of these tests. Twelve tests at each orientation were performed with unidirectionally reinforced specimens. The test matrix for both longitudinal and transverse specimens allowed four tests at each of three temperatures, 649°C, 760°C, and 871°C, over a range of stress. All creep strain versus time curves are shown in Appendix A. The goal of this testing was to determine the effect of stress on creep life at a constant temperature. Figures 10 and 11 show the impact of creep stress on life for both longitudinal and transverse specimens, respectively.

The longitudinal data in Figure 10 shows a great deal of scatter. The isotemperature lines are very flat. This might indicate a stress "threshold" in longitudinal creep, below which lives are infinite and above which lives are short. If longitudinal creep is actually a process in which the matrix creeps and transfers load to the fiber reinforcement, this threshold behavior is understandable. Below the threshold the fibers in the composite are capable of bearing all the creep stress alone and are never loaded to their ultimate tensile stress. Above this threshold, at some point in the transfer of load from the matrix to the fiber, the fiber is loaded to its maximum tensile strength and failure occurs. The scatter in the creep data might be partially attributed to the scatter in tensile strength. More testing and analysis need to be undertaken in this area to understand the process of longitudinal creep fully.

The transverse creep results shown in Figure 11 did not correlate well to a Larson-Miller curve. However, it is possible to model the data using an empirical relationship described by Monkman and Grant* that shows that for a given alloy there is a linear dependence between the log of rupture life and log of minimum creep rate.

$$t_R \, \varepsilon_S^d = K \qquad (1)$$

$$\log t_R + d \log \varepsilon_S = \log K \qquad (2)$$

If it is assumed that an Arrhenius type of relationship between the steady-state creep rate and temperature exists, a general equation that relates creep rate, stress, and temperature can be written

$$\varepsilon_S = A \, \sigma^b \exp(-Q/RT) \qquad (3)$$

---

*F. C. Monkman and N. J. Grant, American Society of Testing Procedures, Vol 56, pp. 593-620, 1956.

Table 5.
Creep-rupture results for unidirectionally reinforced SCS-6/Ti-24Al-11Nb composite.

Specimen	Stress --MPa	Temperature --°C	Rupture life --hr	Total strain--%
Longitudinal				
15L-11	551.6	649	0.05	14.4
26L-3	551.6	649	476.2	1.8
26L-2	517.1	649	752.4	1.9
16L-9	482.7	649	915.2(1)	0.35
16L-16	482.7	760	187.2	2.1
16L-3	448.2	760	147.8	1.6
15L-9	413.7	760	99.5	1.7
26L-1	413.7	760	2.0(2)	-----
15L-3	413.7	871	3.0	1.9
16L-21	379.2	871	2.5	---
26L-4	344.8	871	24.8	---
15L-6	310.3	871	30.5	3.0
Transverse				
25T-4	89.6	649	1.7	---
25T-2	69.0	649	34.4	9.3
25T-5	55.2	649	64.2	7.3
24T-4	34.5	649	408.7	12.2
24T-9	48.3	760	12.7	18.6
15T-2	34.5	760	79.3	12.1
15T-9	27.6	760.0	------Failed test-------------	
24T-8	20.7	760	1000.6(1)	76.6
25T-7	27.6	871	16.1	124.7
15T-10	20.7	871	1008.0(1)	---
24T-7	13.8	871	1079.7(1)	---
15T-8	6.9	871.0	------Failed test-------------	
Cross ply ([0 deg/90 deg]$_s$)				
32-3	296.5	760	16.1	2.6
33-1	296.5	760	20.6	1.5
32-10	186.2	760	1005.4 (1)	----
33-2	186.2	760	1001.9 (1)	----

Table 5. (cont)

Specimen	Stress --MPa	Temperature --°C	Rupture life --hr	Total strain--%
Cross ply ([0 deg/±45 deg/90 deg]$_s$)				
35-1	186.2	760	7.3	2.7
45-3	186.2	760	76.2	3.4
35-5	124.1	760	1011.2 (1)	---
45-5	124.1	760	1011.3 (1)	---

Notes:
1. Specimen unloaded prior to rupture.
2. Specimen failed at extensometer tip.

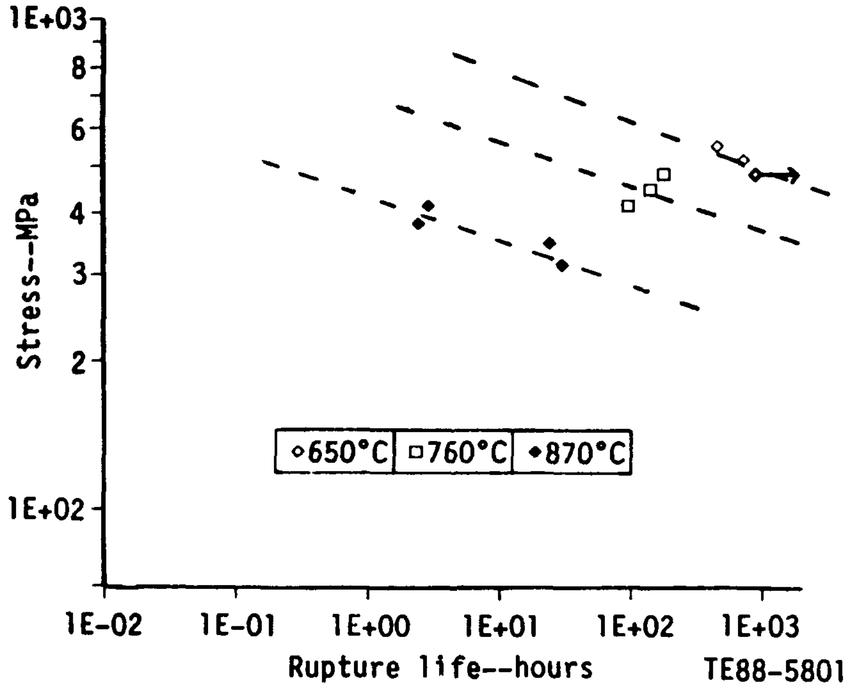

Figure 10. Creep stress as a function of rupture life for longitudinal SCS-6/Ti-24Al-11Nb composite. (Dashed lines represent a linear regression to constant temperature data with averaged slopes.)

Combining equation (3) with (1) produces an equation that describes the dependence of rupture life on stress and temperature

$$t_R = K \;/\; (A\ \sigma^b \exp(-Q/RT))^d \tag{4}$$

Figure 12 shows a plot of rupture life as a function of stress for 649°C, 760°C, and 871°C for the above model. The experimental data agree well, particularly at the lower temperature, with the model predictions. At 871°C the

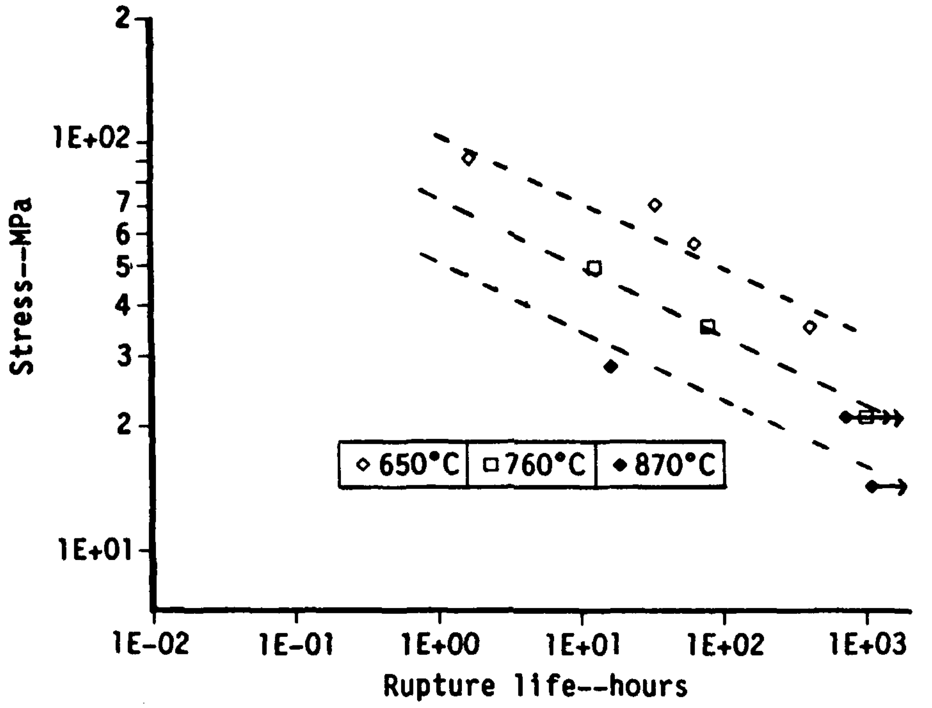

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Figure 11. Creep stress as a function of rupture life for transverse specimens of SCS-6/Ti-24Al-11Nb composite. (Dashed lines represent a linear regression fit to constant temperature data with averages slopes.)

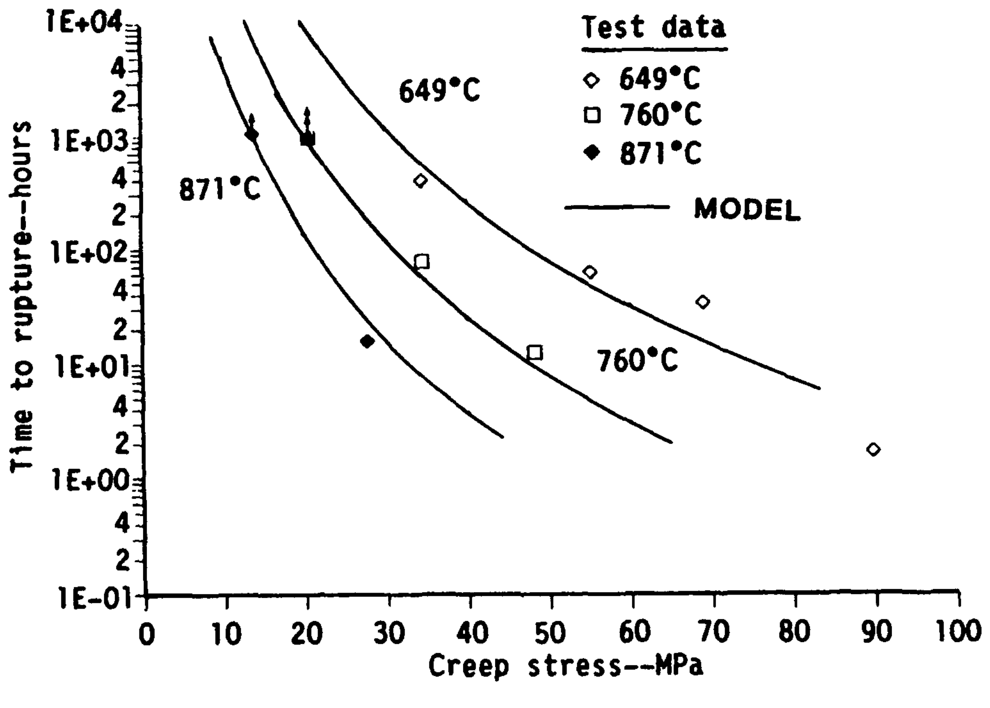

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Figure 12. Rupture life versus creep stress of actual transverse SCS-6/Ti-24Al-11Nb experimental data (points) with a model based on a modified Monkman-Grant equation (lines).

matrix is extremely ductile and acts superplastic. This behavior may explain the lack of correlation between the model at that temperature and the experimental data.

Figures 13 and 14 show typical longitudinal and transverse creep fractures, respectively. In the longitudinal fracture the matrix is ductile and there is separation between the fibers and matrix. The transverse specimens demonstrate a tremendous amount of ductility.

Four specimens of each cross ply lay-up were selected for creep testing. Duplicate tests were conducted at two different stresses at 760°C. Figure 15 shows a comparison of the stress rupture lives of the cross ply specimens with longitudinal and transverse specimens tested at the same temperature. The slope of the stress-life line for the cross ply data is similar to that for longitudinal tests. Also, the relative creep strength of each configuration falls as expected, with the 0 deg/90 deg lay-up higher in strength than the 0 deg/±45 deg/90 deg lay-up.

4.2.2 SCS-6/Ti-25Al-10Nb-3V-1Mo

Table 6 lists the results of four creep rupture tests on longitudinal SCS-6/Ti-25Al-10Nb-3V-1Mo. Four creep tests on transverse specimens in the same system were also planned, but the transverse material proved impossible to test. One specimen was fractured in transportation to the test facility, and the remaining three broke during test setup. The behavior of the longitudinal specimens is similar to that of the composite with the Ti-24Al-11Nb matrix. Figure 16 illustrates the stress-life relationship for longitudinal composite specimens of each matrix. The Ti-25-10-3-1 matrix data falls on the Ti-24-11 curves. The creep strain versus time curves for these tests are in Appendix A.

4.3 FATIGUE CRACK INITIATION BEHAVIOR

The panels from which fatigue specimens for Task II and VI were machined were inspected ultrasonically for internal flaws. No damaged areas were found on any panel. Specimen design and fabrication procedures were modified from those proposed originally. It was determined through research and experience that smaller specimens than those first designed can be used. The modified specimen design is shown in Figure 1. It has also become apparent that the tabs

Table 6.
Creep-rupture results for unidirectionally reinforced SCS-6/Ti-25Al-10Nb-3V-1Mo composite.

Specimen	Stress --MPa	Temperature --°C	Rupture life --hr	Total ;ain--%
		Longitudinal		
28L-1	620.6	649	58.4	1.3
30L-7	620.6	649	416.2	0.9
28L-8	503.3	760	11.4	3.4
30L-10	503.3	760	121.5	2.7

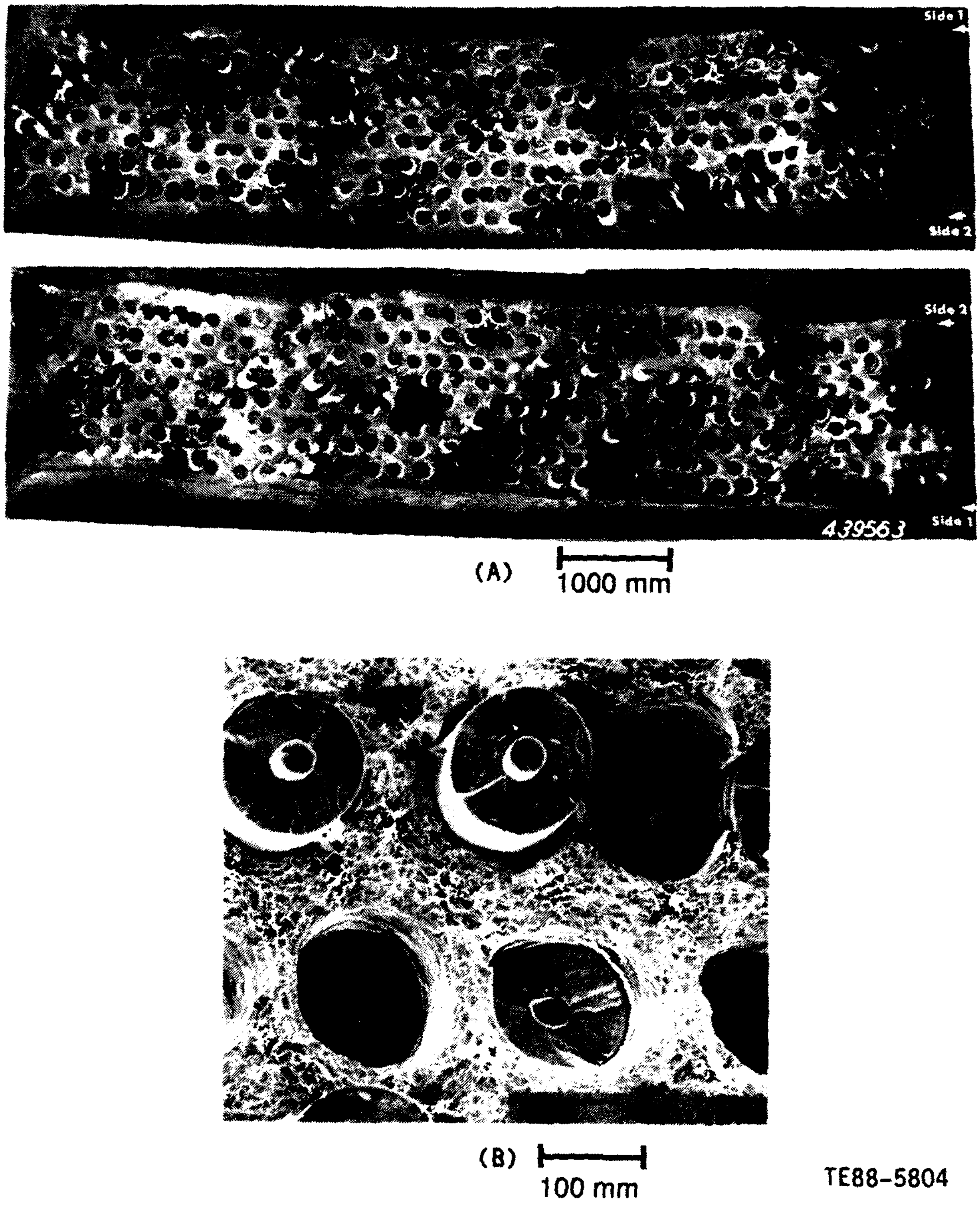
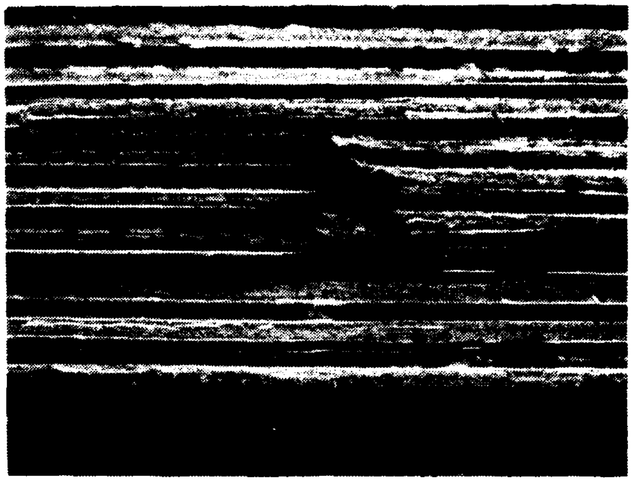
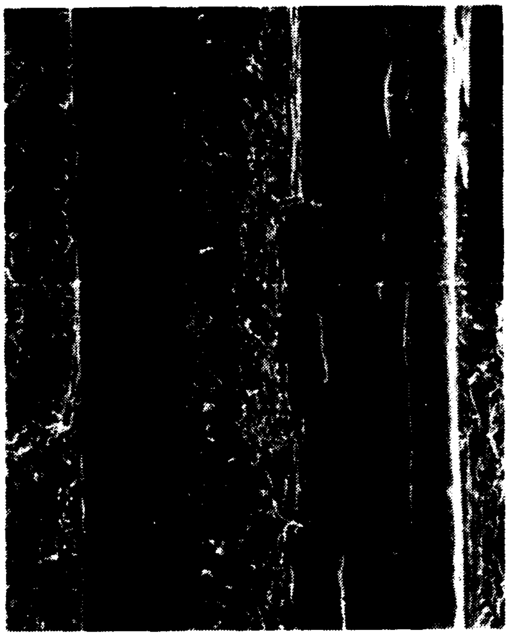


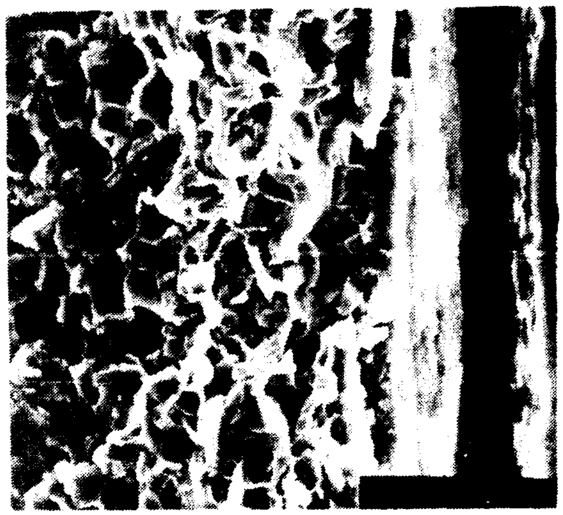
Figure 13. Typical creep fracture of a longitudinal SCS-6/Ti-24Al-11Nb composite. View (A) shows opposing halves of the fracture and (B) a higher magnification of the fracture surface.



(A)



(B)



(C)

TE88-5805

Figure 14. Typical creep fracture of a transverse SCS-6/Ti-24Al-11Nb composite (specimen 24T-9 tested at 760°C and 48.3 MPa). View (A) shows the general fracture structure and views (B) and (C) are higher magnification photos of the fracture.

attached to the grip area of the specimen are not necessarily required and can result in stress concentrations that cause failure in the grip region. For this reason, tabs were not used in testing. Instead, a reduced gage section was cut into each specimen. The radius of curvature in the shoulder area is that prescribed by the American Society of Testing and Materials (ASTM). The notched specimen (shown in Figure 17) is 2.5 cm wide rather than 3.8 cm and has a center hole that results in a K_t of approximately 2.5. All specimens were sectioned from the panels with a diamond saw. Gages were ground in with

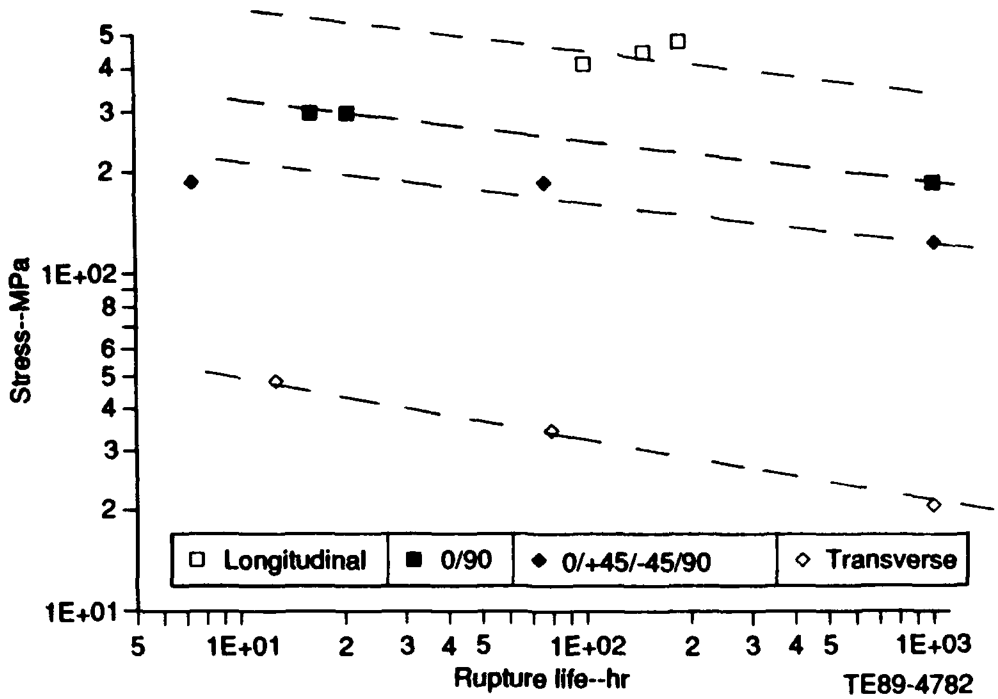


Figure 15. Stress as a function of rupture life for SCS-6/Ti-24Al-11Nb composite showing the relationship between fiber lay-up configurations.

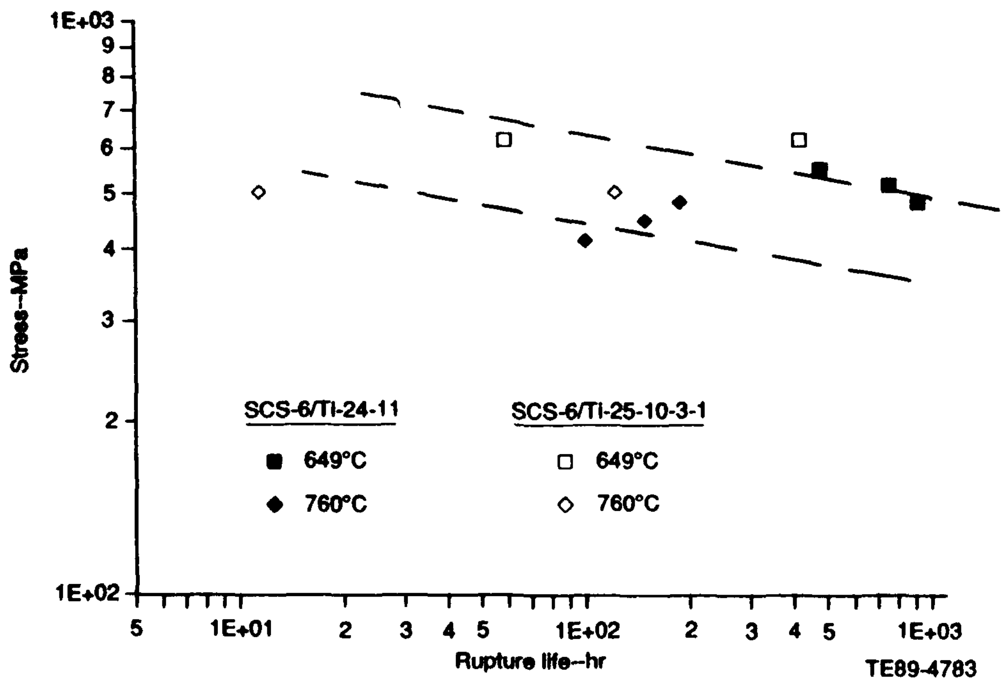


Figure 16. Stress versus creep life of SCS-6/Ti-25-10-3-1 composite compared with that of SCS-6/Ti-24-11.

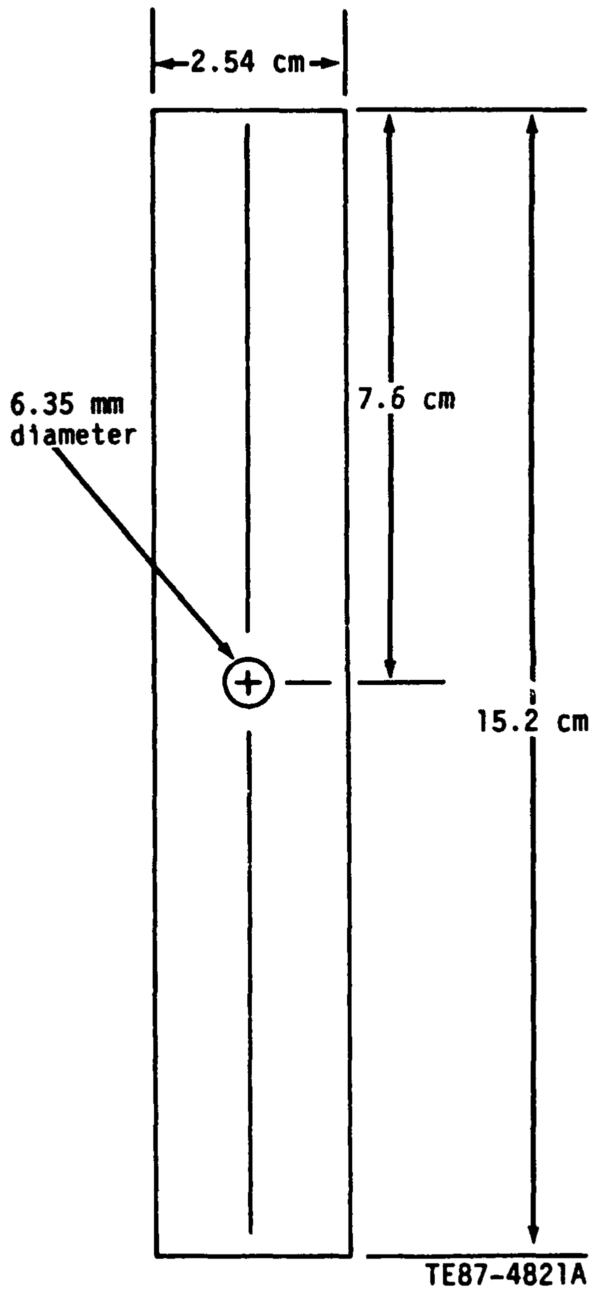


Figure 17. Notched fatigue specimen for fiber-reinforced composite.

diamond grinding wheels to avoid the subsurface damage associated with wire electrodischarge machining (EDM). After grinding, all edges were longitudinally hand polished. Experience has shown that this preparation technique gives the most reproducible test behavior.

The test matrix for investigation of fatigue crack initiation in SCS-6/Ti_3Al composite for Task II is given in Table 7. This matrix of 120 tests allowed the evaluation of the effect of several factors on the fatigue life of this material. The influence of fiber orientation on the fatigue life was studied by testing specimens with fibers at 0 deg (longitudinal), 90 deg (transverse), and 45 deg to the loading direction. The specimens manufactured with a center hole in the gage were tested to determine the notch sensitivity of the composite. Other factors that were examined include the effect of temperature, frequency, and R-ratio on fatigue life. High cycle fatigue tests were performed to determine the 10^7 cycle threshold stress.

The Task VI effort included 10 tests at 20 cpm, R = 0.10, and 760°C and under strain control of longitudinally oriented SCS-6/Ti-24Al-11Nb, and five LCF tests under the same conditions for each of two cross-ply configurations, $[0\ deg/90\ deg]_s$ and $[0\ deg/\pm45\ deg/90\ deg]_s$. Thirteen high cycle fatigue tests were also performed at 760°C and 30 Hz in load control: five on longitudinal specimens, four on [0 deg/90 deg] cross-ply specimens, and four on [0 deg/±45 deg/90 deg] specimens.

All the fatigue tests of unnotched specimens at a frequency of 20 cpm were run in strain control. The load versus time history was monitored to determine if any change in the compliance of the specimen could be detected when crack initiation occurred. Bolt hole specimens (K_t = 2.5) and those tested at 30 Hz were run in stress control. Dual diametral extensometry was employed to measure a compliance change in bolt hole specimens tested at 20 cpm. Periodic hysteresis loops were recorded for all tests performed under strain control. R-ratio referred to here is the ratio of the minimum to maximum controlling parameter (i.e., in strain control, the minimum to maximum strain). The tabulated data for all the fatigue initiation tests are given in Appendix B.

4.3.1 Effect of Temperature and Orientation on Fatigue Initiation

Figure 18 shows the strain range versus life behavior of longitudinal specimens tested at 26°C, 316°C, 649°C, and 760°C. Both the 26°C and 316°C data fall on the same curve, but there is some significant reduction in strain range at 649°C and 760°C. This result differs markedly from that for 45 deg and transverse specimens shown in Figures 19 and 20, respectively. The strain range at a given fatigue life is higher at 649°C than at room temperature for both orientations. This could be due to the additive effect of a brittle matrix at room temperature and a weak fiber-matrix interface.

The room temperature behavior of specimens tested at different orientation is as expected. In Figure 21 the longitudinal specimens had the highest st.ain range as a function of fatigue life with 45 deg and transverse data falling lower. At 649°C, though, the longitudinal and 45 deg specimens show similar strain-life behavior, but the transverse data fall at a lower strain range (Figure 22). This indicates that the weak interface continues to play a roll in the specimen fatigue life even at 649°C.

Table 7.
Fatigue initiation test matrix (number of tests/condition).

Effect of temperature and orientation

Temperature	Fiber Orientation 0 deg	45 deg	90 deg
25°C	10	5	10
310°C	5	-	-
650°C	10	5	10

*R = 0.10, 20 cpm, K_T = 1

Effect of notches

	Longitudinal		Transverse	
Temperature	K_T = 1	K_T = 2.5	K_T = 1	K_T = 2.5
25°C	10	5	10	5
650°C	10	5	10	5

*R = 0.10, 20 cpm

Effect of R-ratio

	25°C		650°C	
R-ratio	K_T = 1.0	K_T = 2.5	K_T = 1.0	K_T = 2.5
0.10	10	5	10	5
0.50	5	5	5	5

*20 cpm, longitudinal

Effect of frequency

	Orientation		Notches		Temperature		R = ratio	
Frequency	650°F		650°F		K_T = 1.0		650°C	
	0 deg	90 deg	K_T = 1.0	K_T = 2.5	25°C	650°C	R = 0.10	R = 0.50
20 cpm	10	10	10	5	10	10	10	5
1800 cpm	5	5	5	5	5	5	5	5

(A total of 120 tests)

Room temperature low cycle fatigue (LCF) fractures showed little or no evidence of initiation and growth of fatigue cracks. A typical longitudinal fracture is shown in Figure 23 and a transverse fracture in Figure 24. Careful examination of the interfaces and surfaces showed no discernable initiation or growth regions. The 45 deg orientation was the same. However, at elevated

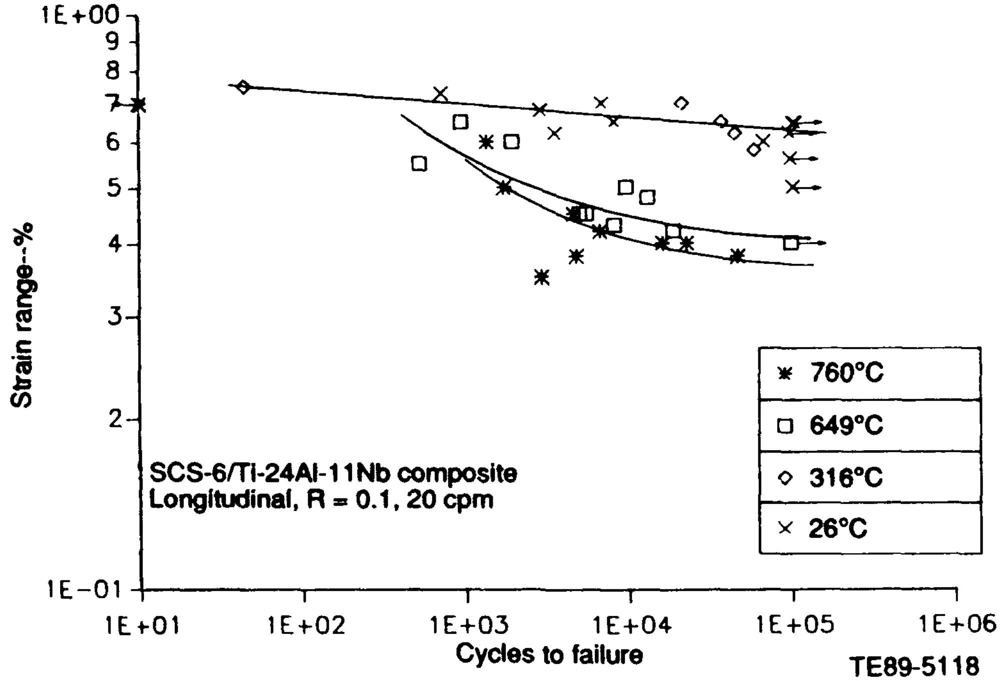


Figure 18. The effect of temperature on the LCF life of longitudinal SCS-6/Ti-24Al-11Nb composite.

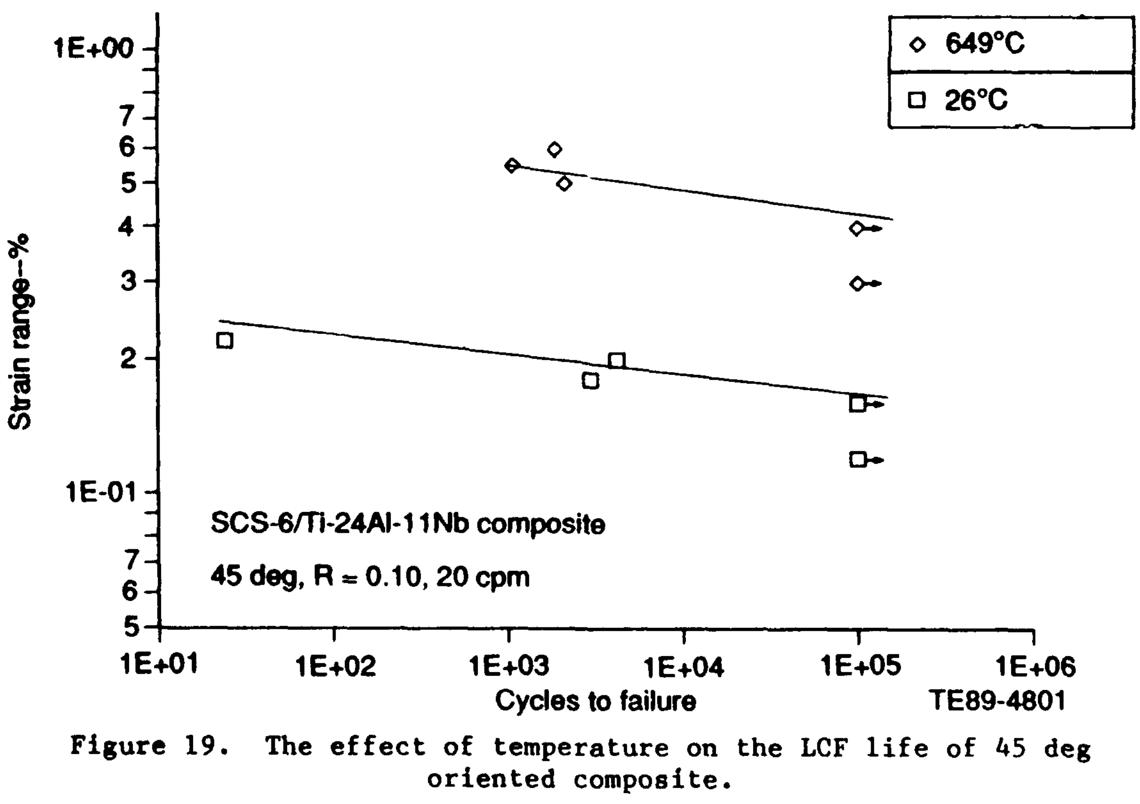


Figure 19. The effect of temperature on the LCF life of 45 deg oriented composite.

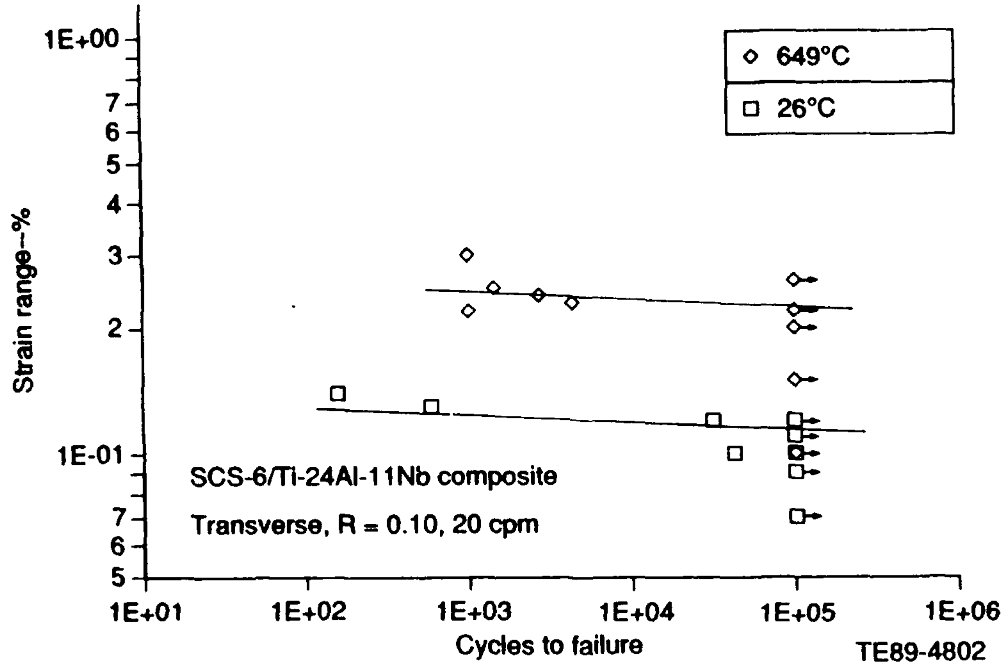


Figure 20. The effect of temperature on LCF life of transverse SCS-6/Ti-24Al-11Nb composite.

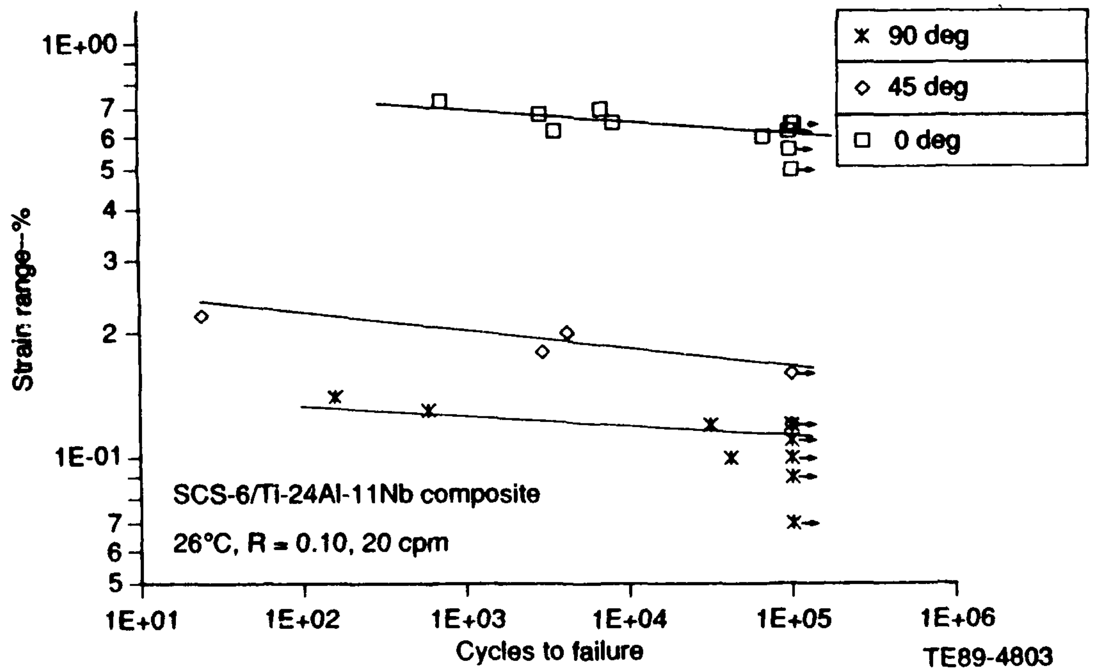


Figure 21. The effect of orientation on room temperatu_e LCF behavior of SCS-6/Ti-24Al-11Nb composite.

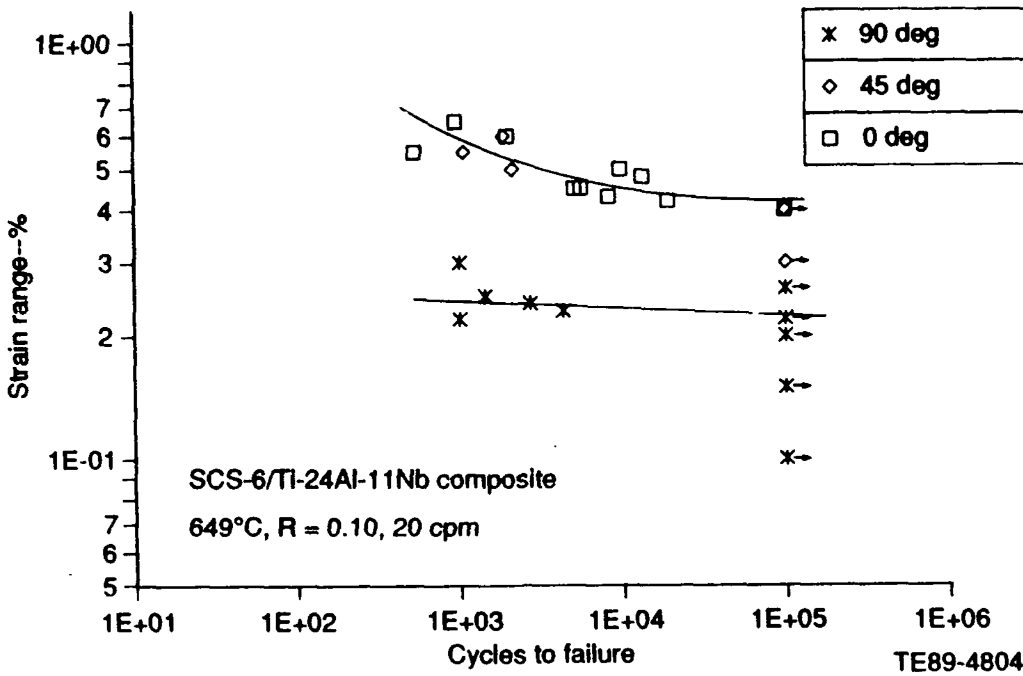
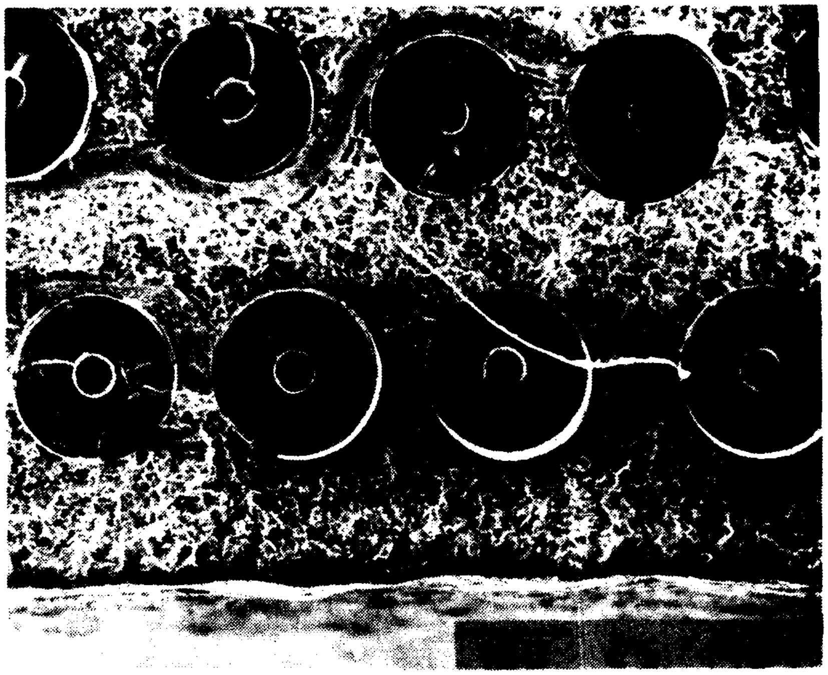


Figure 22. The effect of orientation on the 649°C LCF life of SCS-6/Ti-24Al-11Nb composite.

temperatures, fatigue initiation and growth is readily observable. In Figure 25 the fracture of a 649°C longitudinal specimen is shown. The specimen shows multiple initiations on both edges and corners. The initiations are as expected at surface connected fibers and the surrounding fracture is flat and featureless. The features shown in Figure 26 indicate the variety of initiation sites found in longitudinal specimens. The 45 deg specimen demonstrates similar fracture characteristics to the longitudinal one (Figure 27). The primary initiations occur at the surface of edges and corners and show the same flat fracture morphology. The similarity in initiation and growth of longitudinal and 45 deg specimens is probably a factor in the similarity of their S-N curves. Transverse specimens, though, do show an alternative fracture surface. In Figure 28 there is evidence of multiple fatigue initiations occurring at the fiber-matrix interface and growing into the matrix. The fatigue fracture is characteristically flat, but it emanates from dozens of initiation sites within the cross section of the specimen gage. The large number of initiation sites and relatively short distance required for crack growth may explain the poor fatigue behavior of the transverse composite at 649°C.

Figure 29 shows the strain range versus life plot of the $[0\ \mathrm{deg}/90\ \mathrm{deg}]_s$ and $[0\ \mathrm{deg}/\pm 45\ \mathrm{deg}/90\ \mathrm{deg}]_s$ cross ply fatigue specimens compared with the curve fit to the unidirectional data at 760°C. The cross ply data fall very close to the unidirectional curve, although there are significant differences in the moduli and strengths of these lay-ups. This is an indication that matrix properties, not fiber orientation, determine the fatigue life of the composite system.



(A)

(B)

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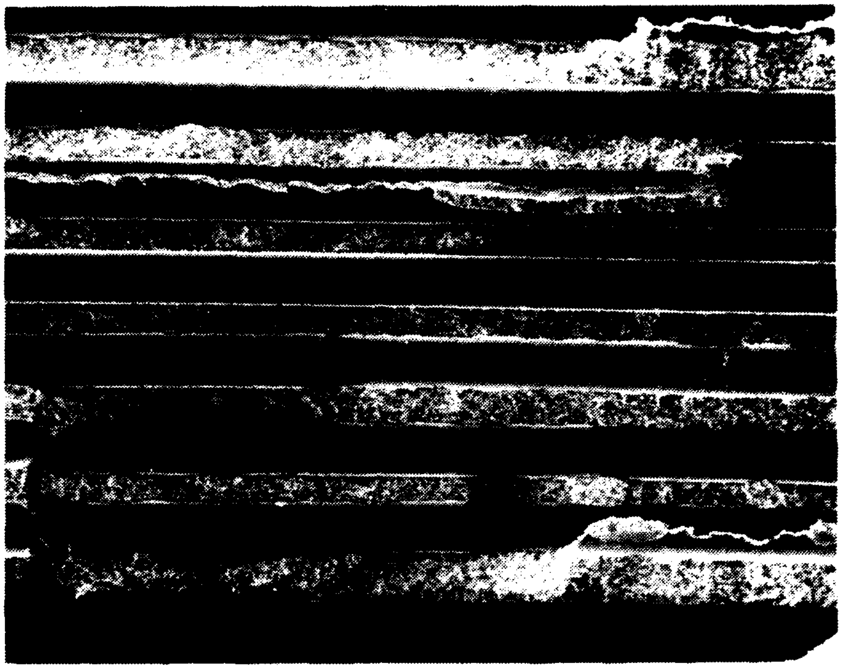
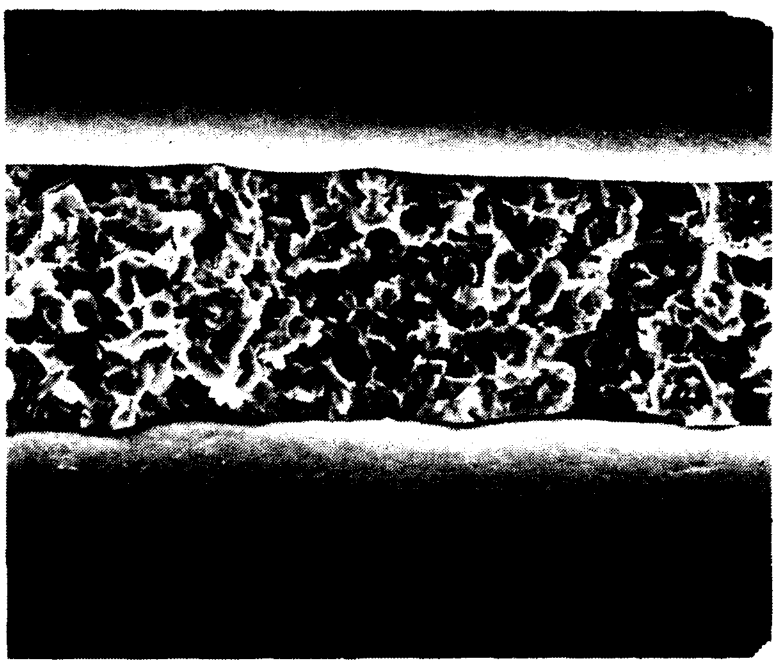
Figure 23. Room temperature LCF fracture of longitudinal SCS-6/Ti_3Al composite. No definite initiation could be identified either at the surface (A) or at the fiber/matrix interface (B).

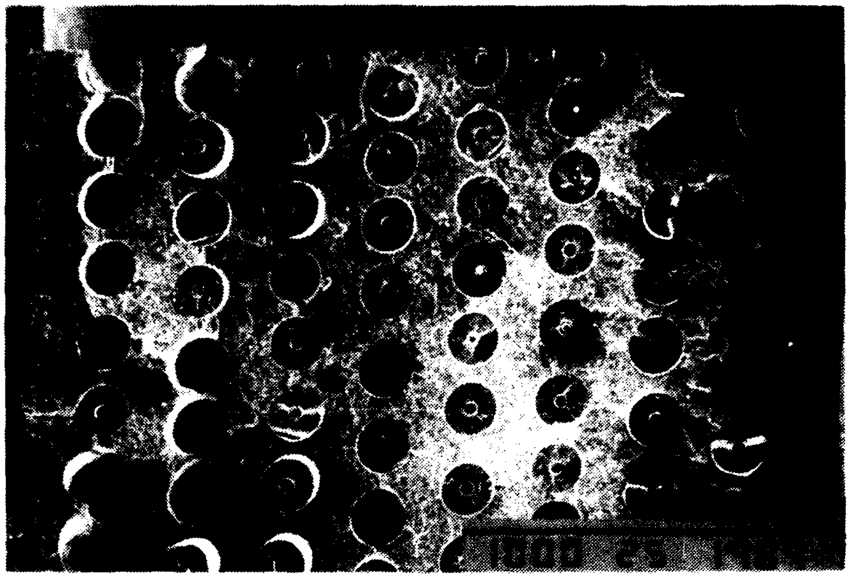


(A)

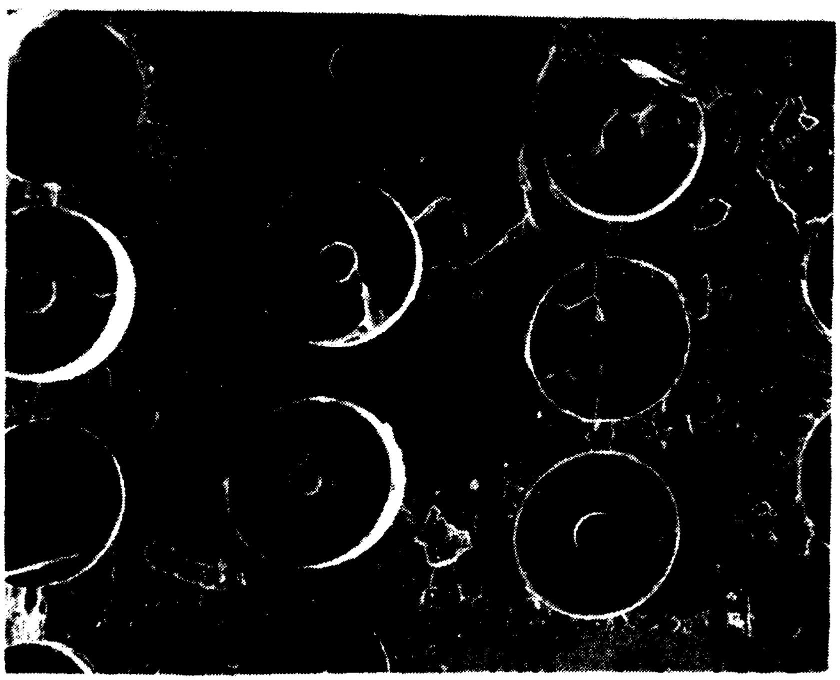


(B) TE89-4792

Figure 24. Room temperature fracture of transverse LCF specimen of SCS-6/Ti_3Al composite. No definite initiation could be identified (A). Matrix fracture is brittle cleavage throughout fracture (B).



(A)



(B)

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Figure 25. Longitudinal LCF fracture at 649°C showing several initiations at edge and corner (A) and a close-up of the edge initiation (B).

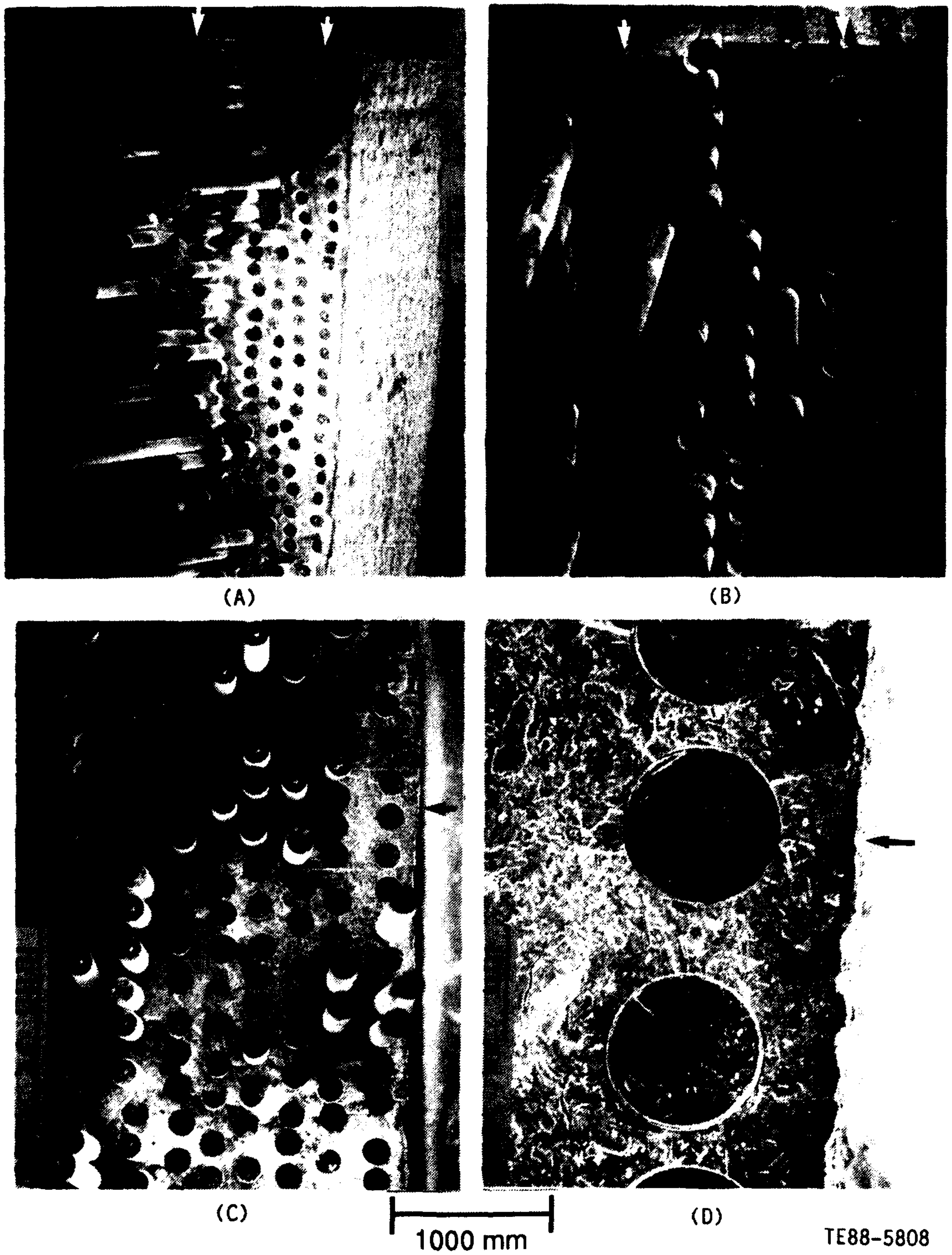
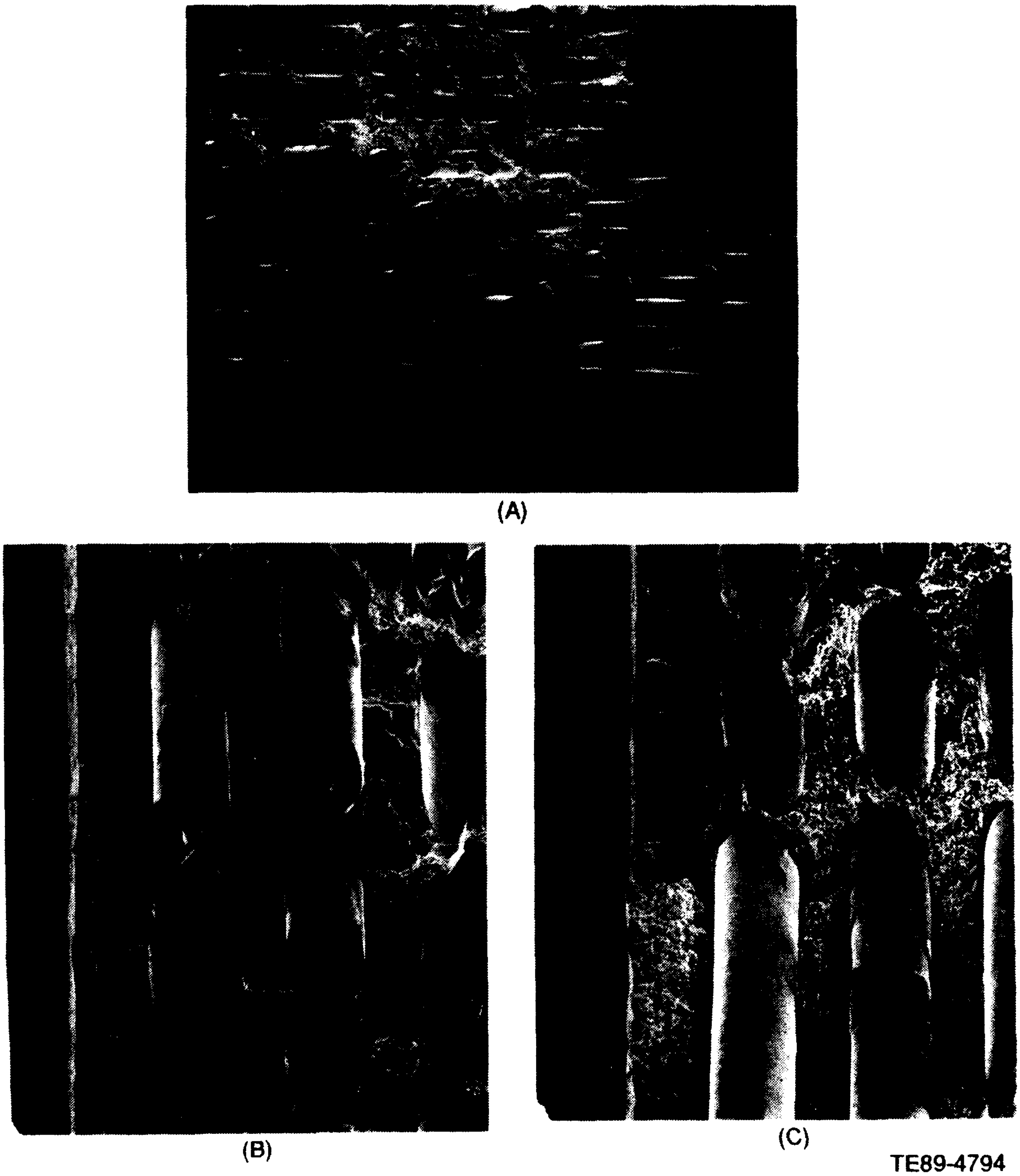


Figure 26. Typical LCF fractures of SCS-6/Ti-24Al-11Nb composite tested at 760°C. Edge initiations are marked with an arrow in (A) and at higher magnification in (B). Views (C) and (D) are low and high magnification photos of a face initiation.



TE89-4794

Figure 27. Elevated temperature (649°C) fatigue fracture of an SCS-6/Ti_3Al specimen with load applied at 45 deg to the fiber direction. The primary initiation occurred at the corner and secondary initiation extended along one face (A). Fatigue fracture is characteristically flat (B) and overload more broken (C).

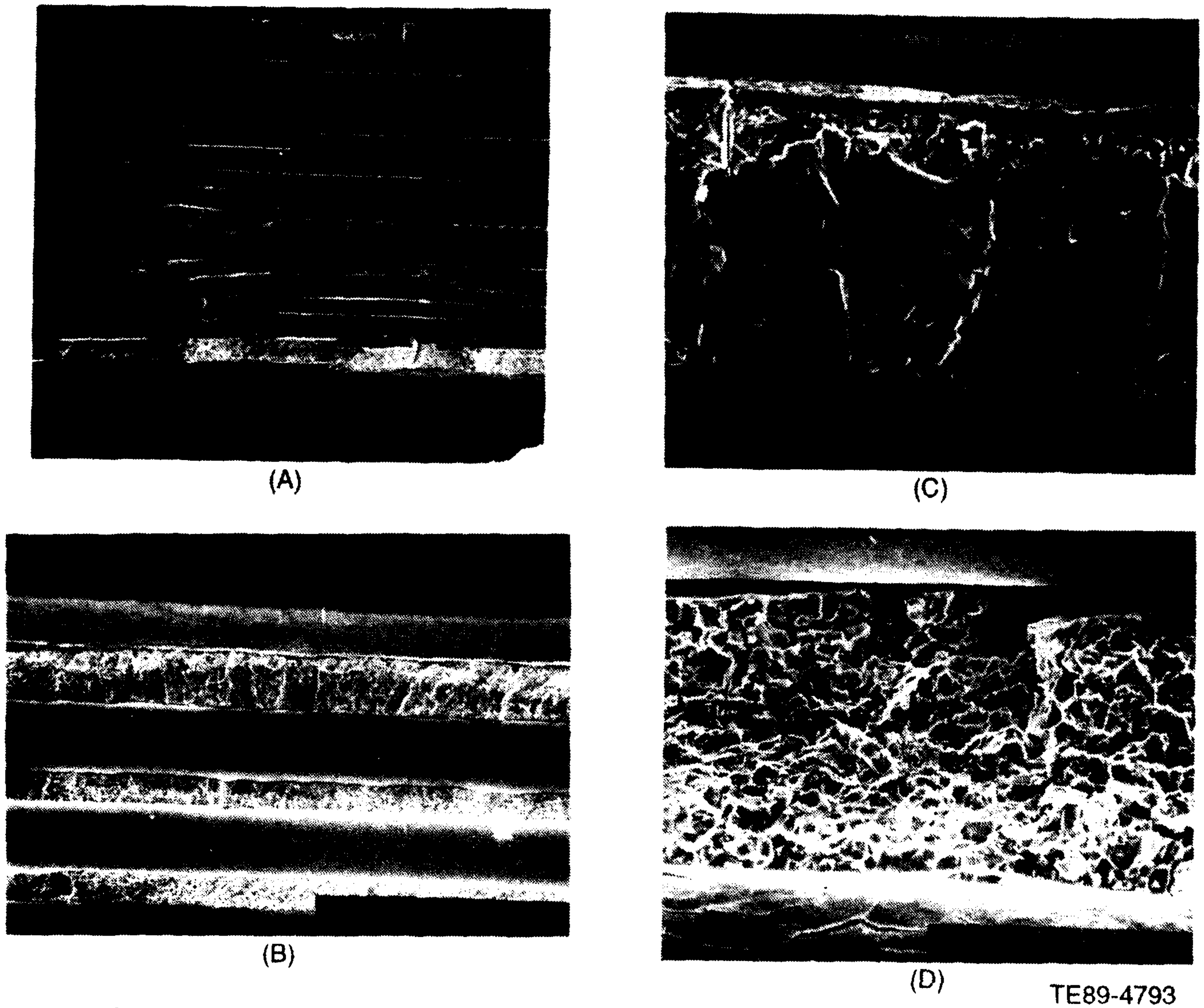


Figure 28. Transverse fracture of 649°C LCF specimen. Multiple fatigue initiations occurred along one face (A). A close-up of one fatigue crack shows initiation from the fiber/matrix interface (B). The fatigue fracture is flat and featureless (C), while overload areas are more ductile in appearance (*D*).

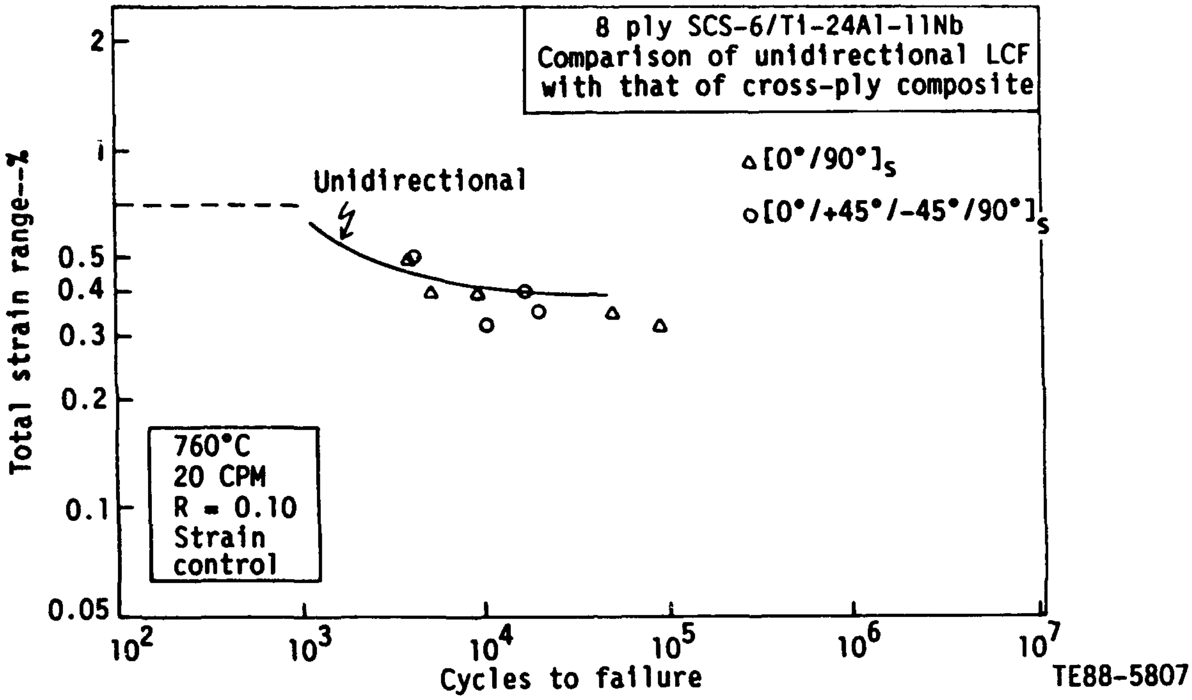


Figure 29. Strain range as a function of cycles to failure of the cross ply (points) and unidirectionally reinforced (line) SCS-6/Ti-24Al-11Nb composite.

Figures 30 and 31 show the normalized modulus and maximum stress as a function of fraction of fatigue life, respectively for typical 760°C tests. The change in modulus and maximum stress over the range of the fatigue life is plotted for the two longitudinal and two of each cross ply configuration with the longest lives. These figures indicate that with the exception of one [0 deg/90 deg]$_s$ specimen, most of the drop in modulus and maximum stress occurs in the first tenth of the fatigue life of a specimen. Also, there is very little difference in the behavior of a unidirectionally reinforced specimen compared with a cross ply specimen. It is possible that the change in compliance indicated by the initial drop in the modulus is due to cracking of the matrix. To verify this hypothesis, fatigue tests must be interrupted to inspect the specimen for cracks.

4.3.2 Effect of Notches on Fatigue Initiation

The effect of a notch on the LCF behavior of both longitudinal and transverse SCS-6/Ti_3Al was examined. Figure 32 illustrates the effect of a circular hole (nominal K_t = 2.5) on the stress range versus life behavior of longitudinal composite at 26°C and 649°C. An apparent reduction in fatigue life coincides with the presence of a bolt hole. This reduction in life is greater than that which would be expected in a cast monolithic material with a comparable notch. The effect of a notch on fatigue behavior may be expressed by a notch sensitivity factor, Q, which is calculated by the following equation:

$$Q = \frac{K_F - 1}{K_t - 1}$$

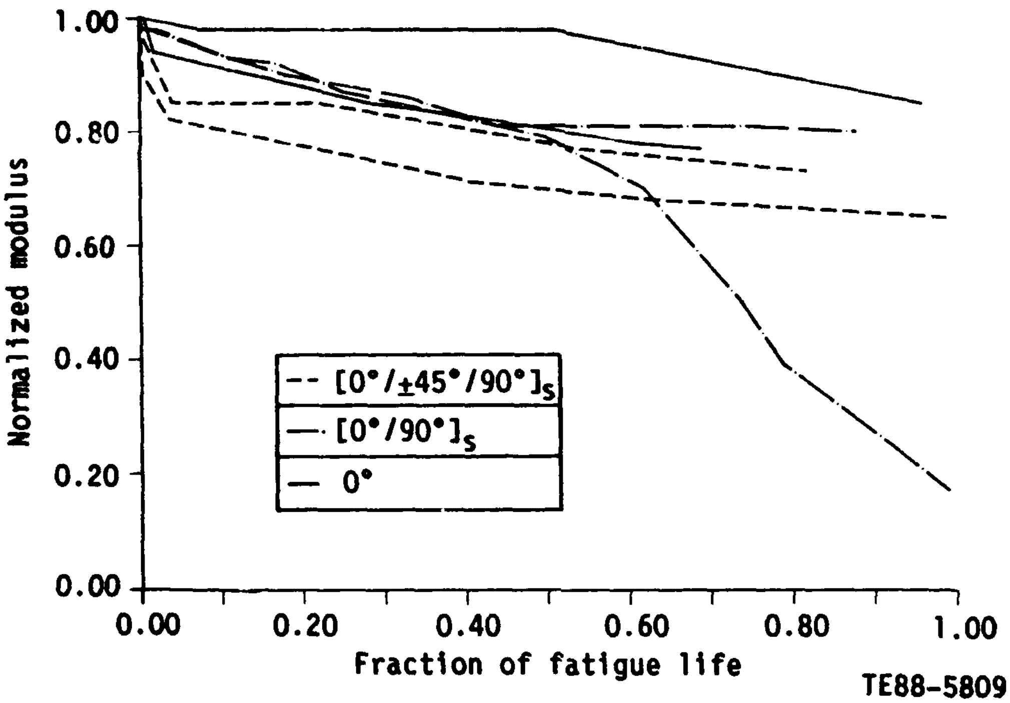


Figure 30. Normalized tensile modulus versus fraction of low cycle fatigue life for the longest lived cross ply and unidirectionally reinforced SCS-6/Ti-24Al-11Nb composite.

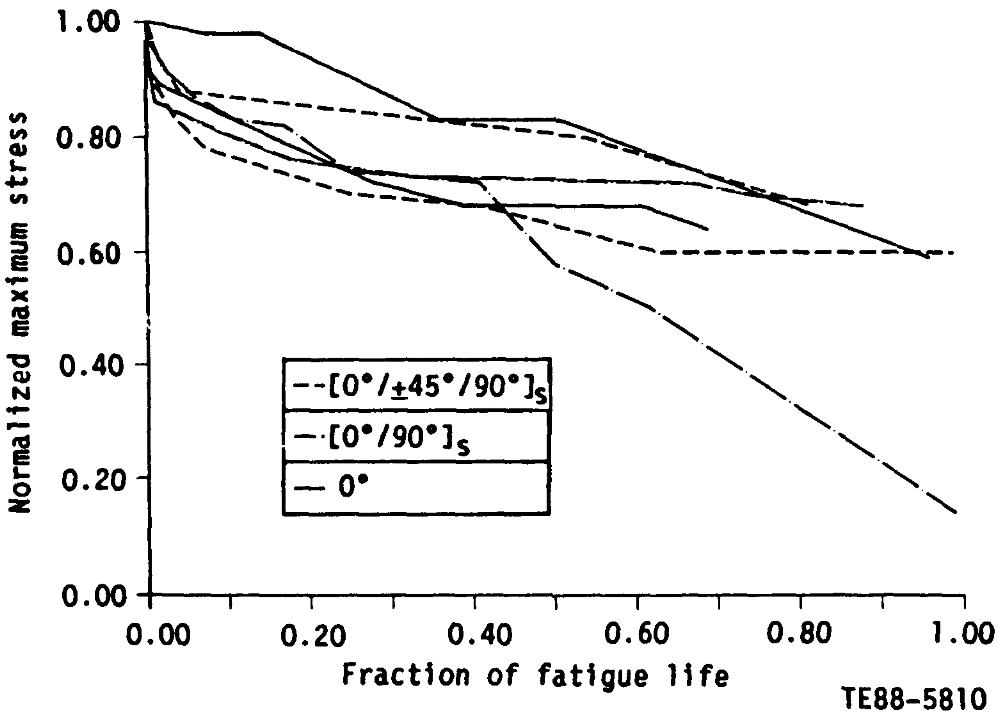


Figure 31. Normalized maximum stress as a function of the fraction of fatigue life for the longest lived cross ply and unidirectionally reinforced fatigue specimens of SCS-6/Ti-24Al-11Nb.

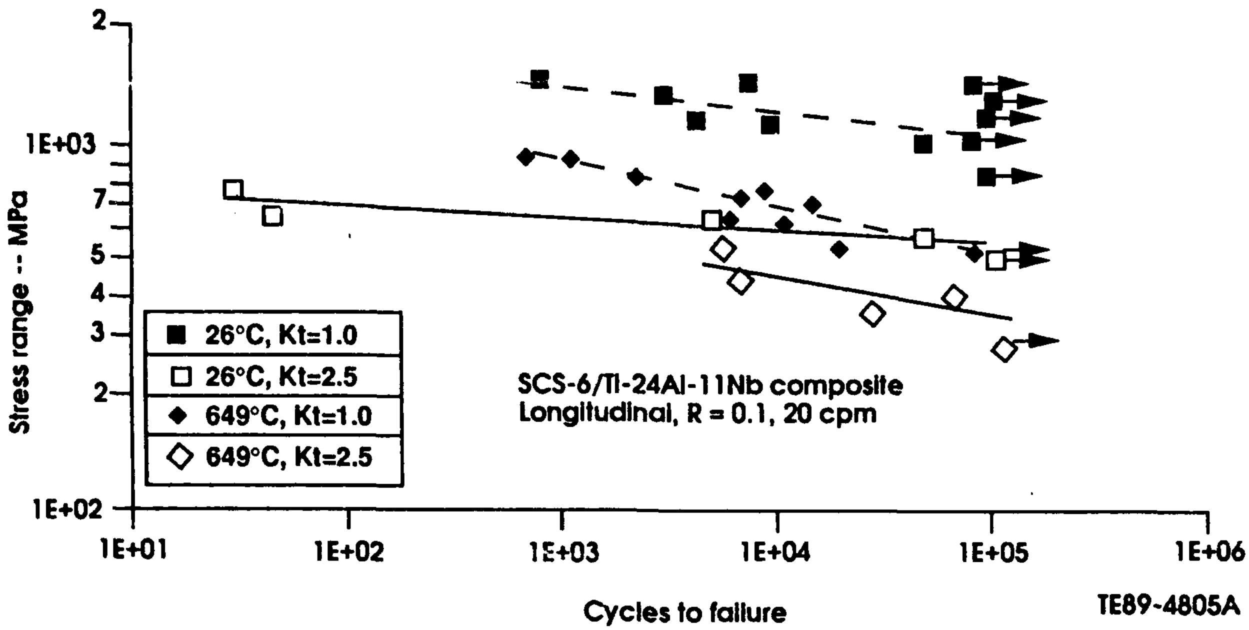


Figure 32. The effect of notches (K_t = 2.5) on longitudinal LCF life of SCS-6/Ti-24Al-11Nb.

where K_F is the fatigue-notch factor or the ratio of the fatigue limit of unnotched specimens to that of notched specimens and K_t is the stress concentration factor. For longitudinal specimens tested at 26°C the value of Q is approximately 0.5 and at 649°C about 0.33. As a basis of comparison, a cast material that has a uniform distribution of inherent defects will have a Q of 0.1 or 0.2. Wrought metals, which, in general, have few defects, are more significantly affected by the presence of a notch and will have Q factors as high as 0.9 or 1.0.

The effect of the notch on transverse fatigue life is shown in Figure 33. It is evident that the bolt hole has no effect on the life of transverse specimens at room temperature. The effects of high residual stress in the matrix and a weak fiber-matrix interface, which runs across the gage and is a large fraction of the cross sectional area, far outweigh any detrimental effect of the bolt hole. At 649°C, however, there is a reduction in fatigue life due to the presence of the bolt hole. The Q associated with this effect is 0.45.

4.3.3 Effect of R-Ratio on Fatigue Initiation

The effect of R-ratio on longitudinal LCF behavior varies with temperature. The room temperature LCF curves for an R of 0.1 and an R of 0.5 are shown in Figures 34 and 35. The fatigue life is plotted versus the strain range of testing and the maximum strain, respectively. By comparing these plots it is evident that fatigue life at 26°C is controlled by the maximum strain of the cycle. Strain range has little or no effect. This could be due to the brittle nature of the matrix at this temperature.

At 649°C there is no correlation of fatigue life with either strain range (Figure 36) or maximum strain (Figure 37). There is some effect of strain range at the elevated temperature. This behavior is more typical of a mono-

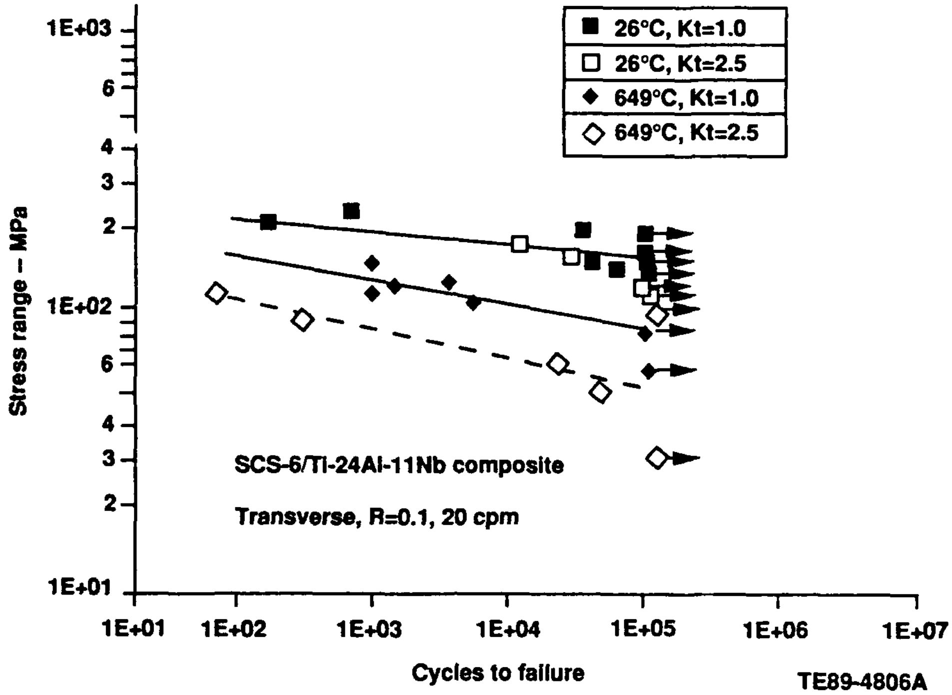


Figure 33. The effect of notches on the transverse LCF behavior of SCS-6/Ti-24Al-11Nb.

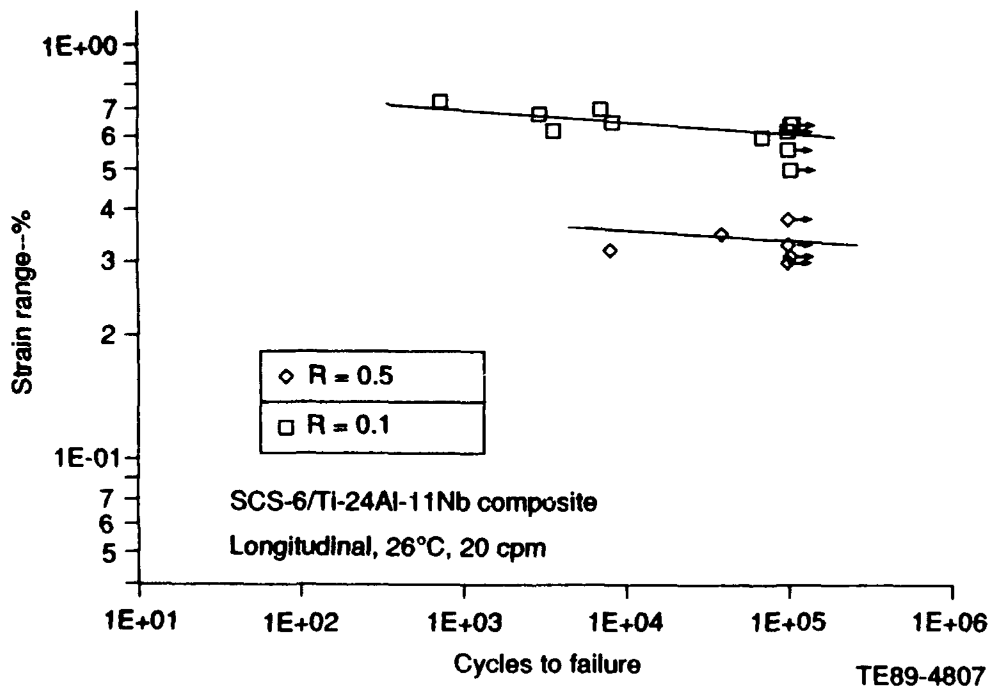


Figure 34. The effect of R-ratio on 26°C LCF life plotted versus strain range for SCS-6/Ti-24Al-11Nb.

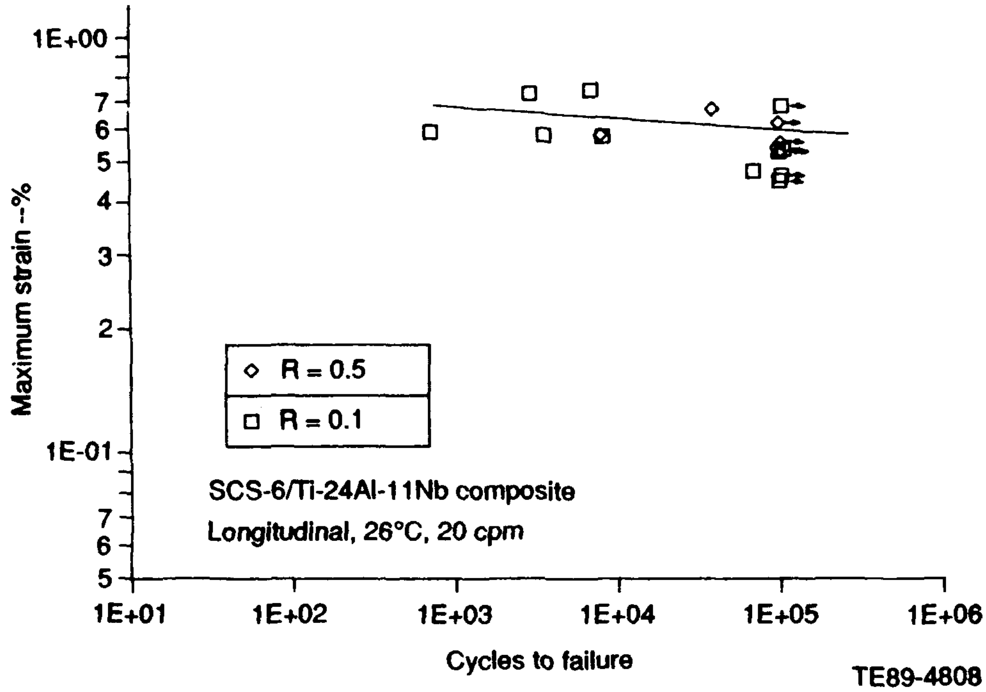


Figure 35. The effect of R-ratio on 26°C LCF lives plotted versus maximum strain.

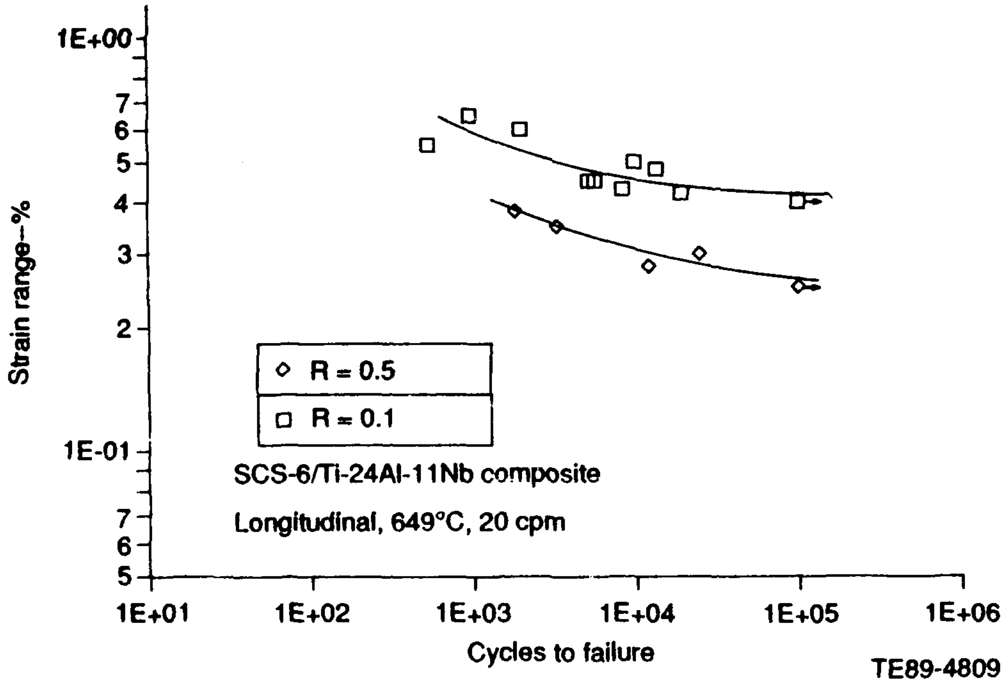


Figure 36. The effect of R-ratio on 649°C LCF life plotted versus strain range for SCS-6/Ti-24Al-11Nb.

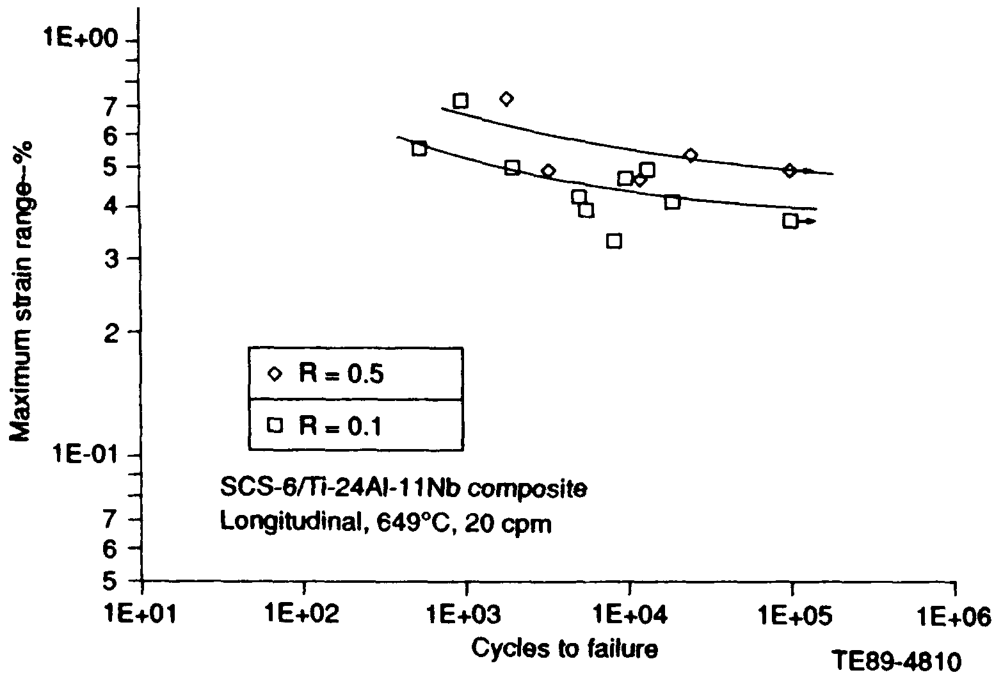


Figure 37. The effect of R-ratio on 649°C LCF life plotted as a function of maximum strain for SCS-6/Ti-24Al-11Nb.

lithic material than that at low temperature in that as R becomes more positive, or the mean strain increases, the measured fatigue limit is greater (Figure 37).

Figures 38 and 39 illustrate the same effect of R-ratio on notched longitudinal specimens. The 26°C data are plotted as two curves in Figure 39; however, there is not a great distinction between the R = 0.1 and R = 0.5 data when plotted against maximum stress.

4.3.4 Effect of Frequency on Fatigue Initiation

Fatigue crack initiation tests were performed at frequencies of 20 cpm and 1800 cpm (30 Hz) to determine the effect of frequency on life. Figure 40 shows a plot of longitudinal specimens tested at 26°C, 649°C, and 760°C at both frequencies. The stress range plotted for the LCF specimens was that measured during testing in strain control. The 30 Hz tests were performed in load control. At room temperature there is no clear evidence of any type of effect of frequency on fatigue life. The individual data points fall on similar curves. At elevated temperature, however, some effect of frequency is evident in the fact that the 30 Hz data at 649°C and 760°C fall on the same curve, but at the lower frequency, 0.33 Hz (20 cpm), the lives of the higher temperature test are below those at 649°C. Transverse specimens tested at 649°C also show no frequency effect (Figure 41). Frequency does not alter the lives of notched specimens either. Figure 42 shows bolt hole and smooth longitudinal specimens tested at 649°C, R of 0.1, and each frequency. The Q factor for these data is the same as that for the lower frequency tests. The higher R-ratio tests are similarly unaffected by frequency. In Figure 43 the R of 0.5 lives measured at 30 Hz fall on the same curve as those measured at 20 cpm. No indication of frequency effects were discovered.

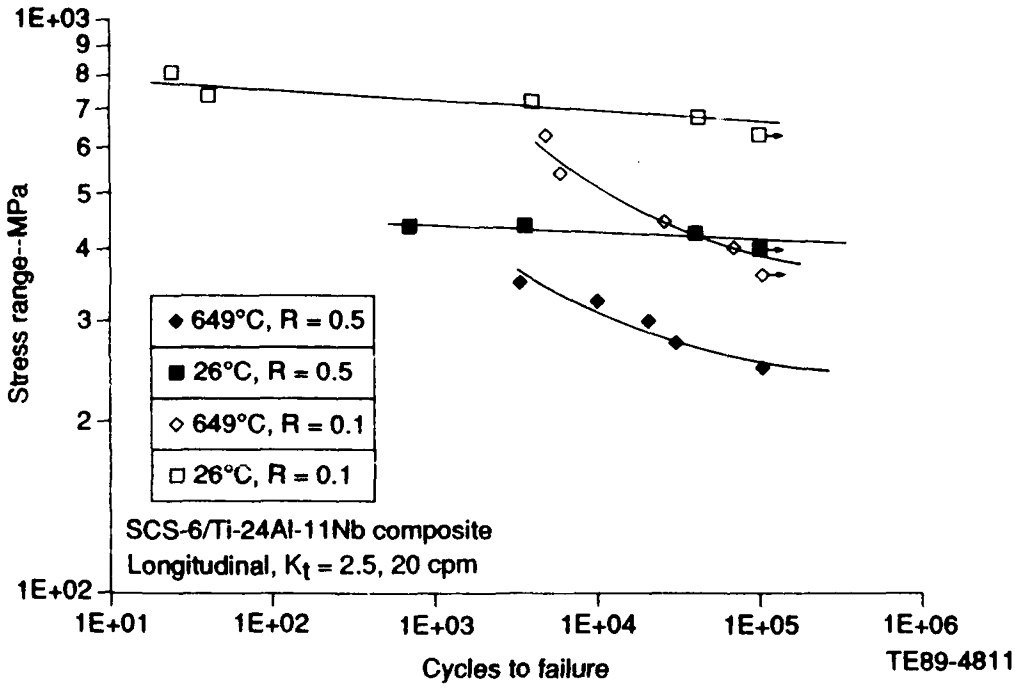


Figure 38. The effect of R-ratio on notched longitudinal LCF specimens plotted versus stress range.

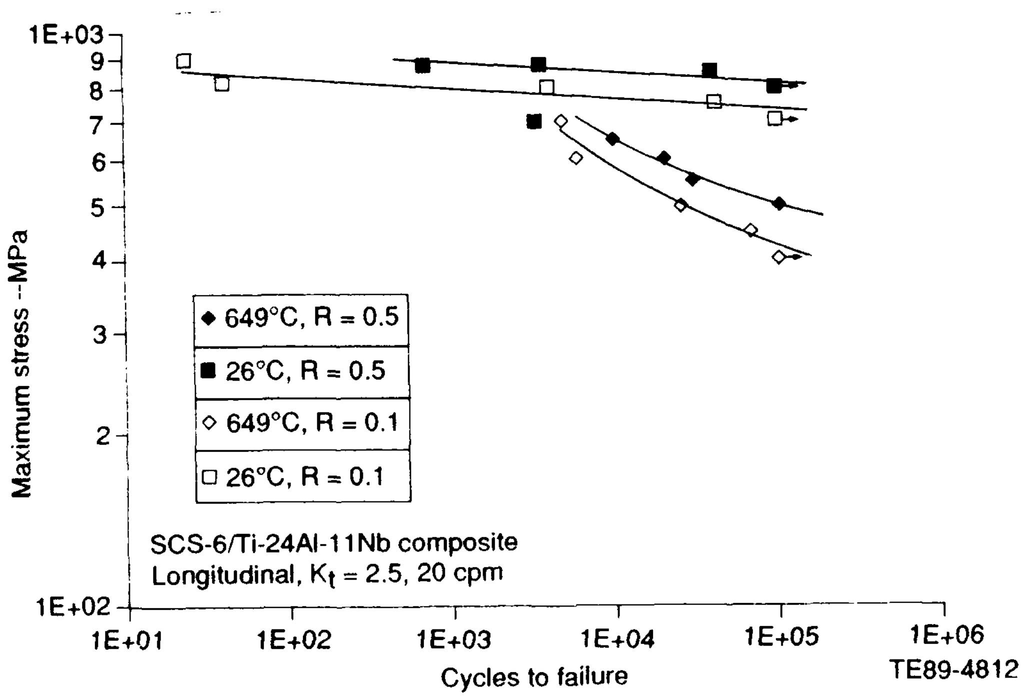


Figure 39. The effect of R-ratio on notched longitudinal LCF specimens plotted versus maximum stress.

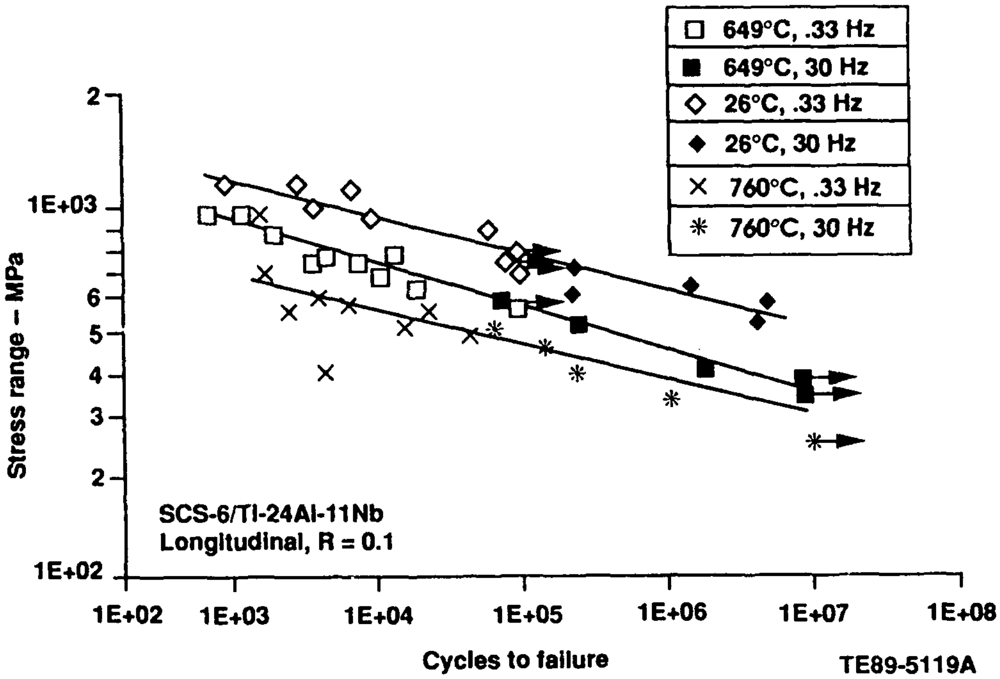


Figure 40. The effect of frequency on longitudinal SCS-6/ Ti-24Al-11Nb fatigue life at 26°C and 649°C.

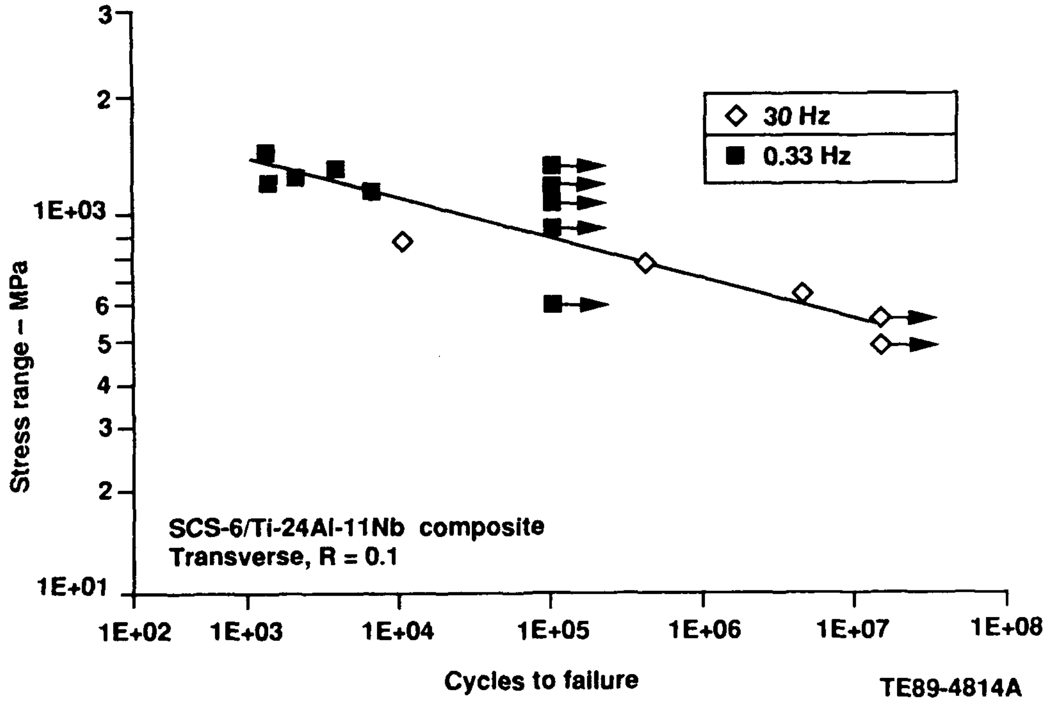


Figure 41. The effect of frequency on the transverse SCS-6/ Ti-24Al-11Nb fatigue life at 649°C.

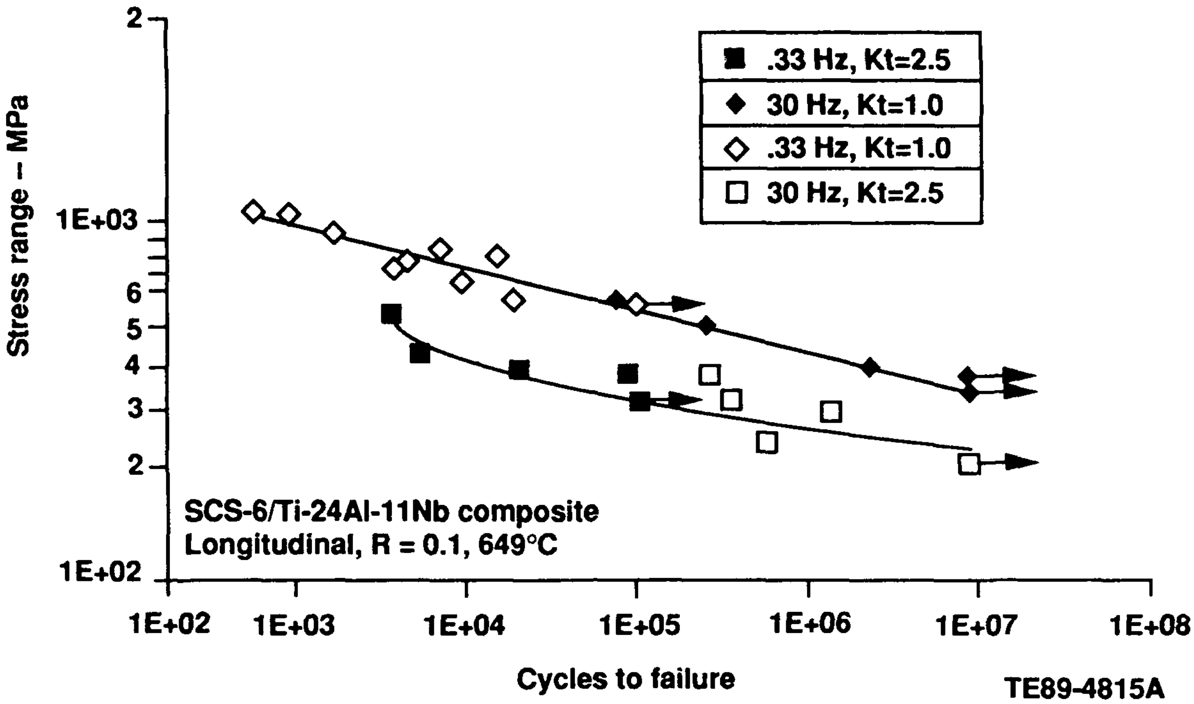


Figure 42. The effect of frequency on notch longitudinal fatigue specimens.

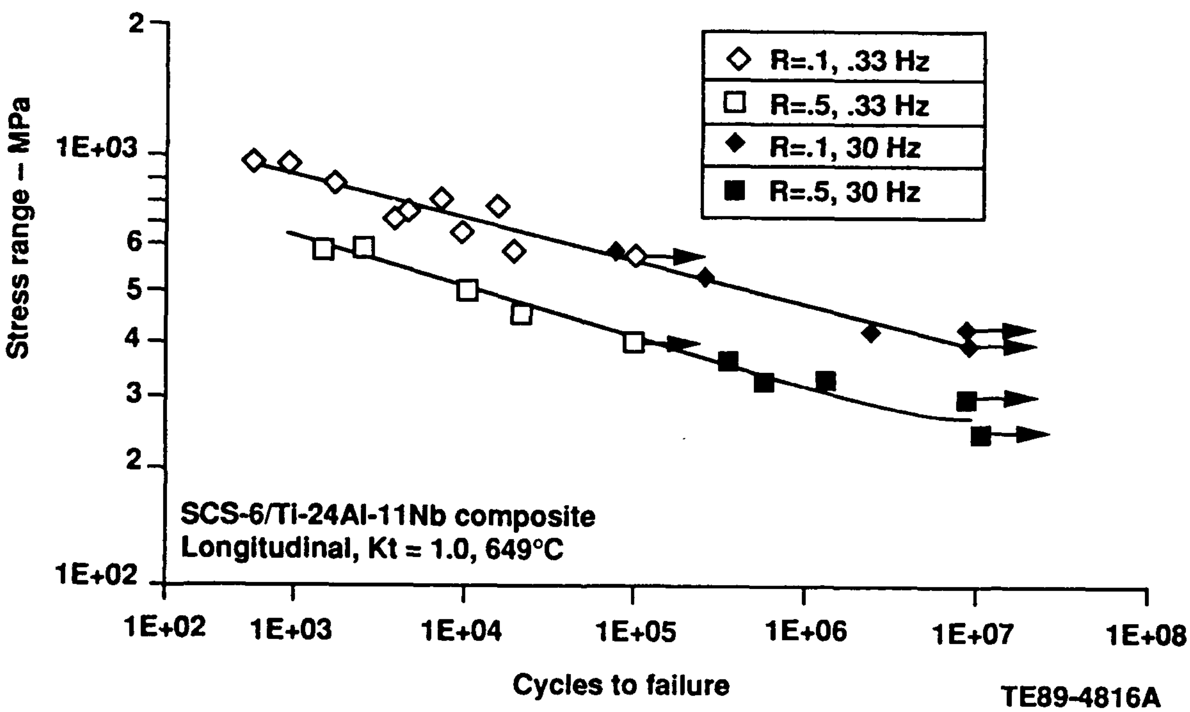


Figure 43. The effect of frequency on longitudinal specimens tested at R = 0.1 and R = 0.5.

At 760°C high cycle fatigue tests were performed on unidirectional and cross-ply composite. The maximum stress as a function of cyclic life for the two cross ply configurations is shown in Figure 44. The curve fit to the unidirectional data is included for comparison. The cross ply specimens behaved as predicted. The [0 deg/90 deg]$_s$ lay-up possessed longer life than the [0 deg/$\pm$45 deg/90 deg]$_s$ at the same maximum stress. The [0 deg/90 deg]$_s$ configuration has twice the number of plies oriented parallel to the load axis than the [0 deg/$\pm$45 deg/90 deg]$_s$, and, since strength is determined primarily by the fraction of 0 deg fibers, the [0 deg/90 deg]$_s$ composite should support higher stresses. If, however, fatigue behavior is controlled by the strain-life characteristics of the matrix, the data would fall on one curve when strain range is plotted as a function of life. Figure 45 shows that this is indeed the case. Strain range for the cross ply tests was calculated by dividing the stress range by the average modulus for each configuration. When both cross ply and unidirectionally reinforced tests are plotted together, the points fall on a single line. Thus, the fiber configuration controls the load carrying capability of the composite, but it is the response of the matrix to strain which controls the composite fatigue life.

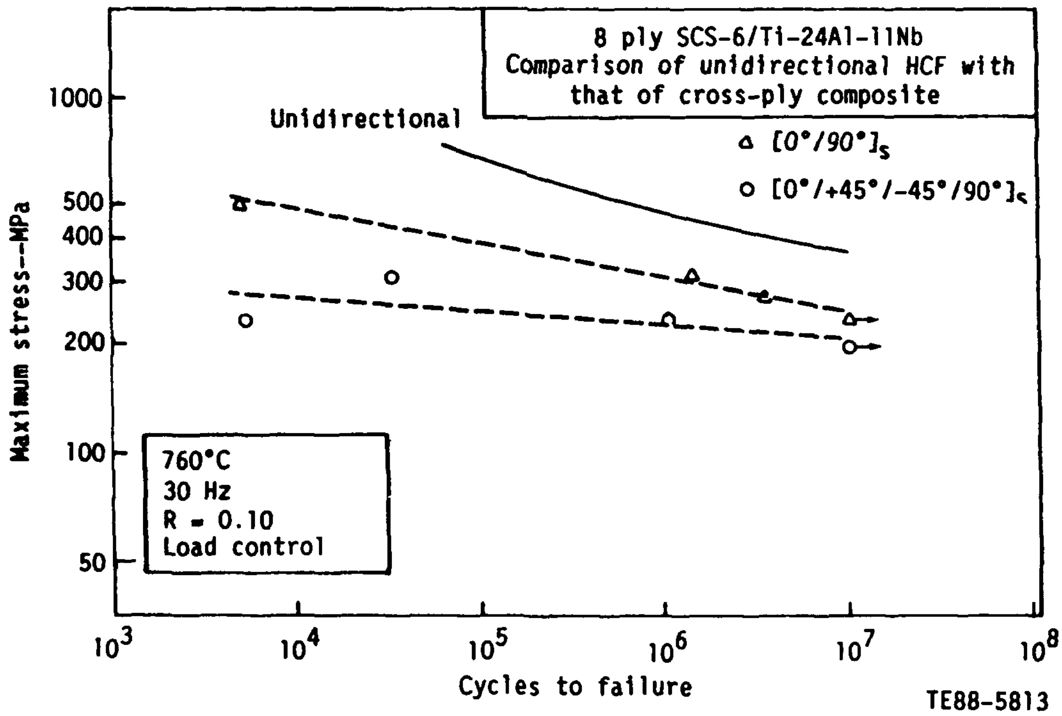


Figure 44. Maximum stress versus cyclic life for cross ply (points) and unidirectionally reinforced (line) SCS-6/Ti-24Al-11Nb tested in high cycle fatigue.

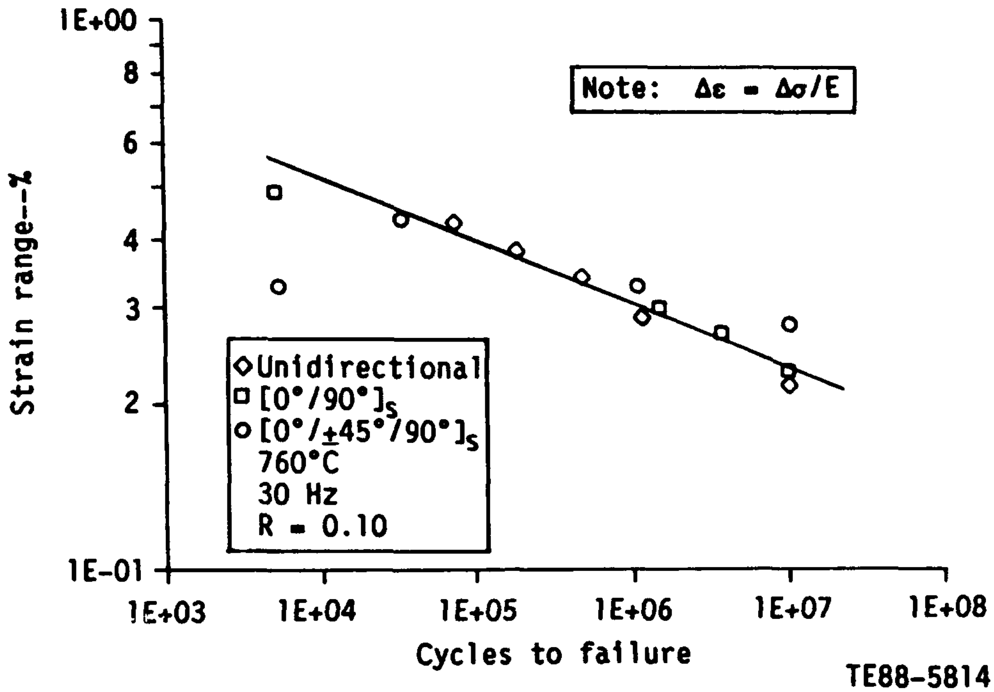


Figure 45. Strain range versus cyclic life for cross ply (points) and unidirectionally reinforced (line) SCS-6/Ti-24Al-11Nb tested in high cycle fatigue.

4.4 FATIGUE CRACK GROWTH BEHAVIOR

The test matrix for the study of fatigue crack growth rate (FCGR) in SCS-6/ Ti_3Al composite is shown in Table 8. The matrix included 24 tests for the examination of the effects of temperature, orientation, R-ratio, and frequency on the fatigue crack growth behavior of this material system.

The tests were performed by Materials Behavior Research Corporation. Initially, two tests on bolt hole type specimens were performed to develop the required test techniques, and those results are plotted in Figure 46. But all 24 tests listed in the table were performed on single edge notch specimens machined from the second lot of composite. The longitudinal specimens were manufactured with a monolithic edge in which starter notches were machined. Crack length during testing was measured both optically and using potential drop techniques. Good agreement was found between the crack length reported by potential drop measurements and the optical measurements made on both longitudinal and transverse specimens.

Duplicate tests were run at each condition. As a test for the applicability of linear elastic fracture mechanics, a different stress level was used for each test of a set. Crack growth rate as a function of stress intensity was calculated using the solution for a SEN specimen with fixed ends as follows:

$$\Delta K = \Delta\sigma_\infty \sqrt{\pi a}\ \left[\frac{5}{(20 - 13(a/w) - 7(a/w)^2)^{1/2}}\right]$$

Table 8.
Fatigue crack growth test matrix.

Number of tests/condition

Effect of R-ratio

Temperature	R-ratio 0.10	0.50	0.80
25°C	2	2	2
650°C	2	2	2

*200 cpm, longitudinal

Effect of orientation and temperature

Orientation	25°C	316°C	650°C
Longitudinal	2	2	2
Transverse	2	2	2

*200 cpm, R = 0.10

Effect of frequency at 650°C

200 cpm	2 cpm	5 min dwell
2	2	2

*Longitudinal, R = 1.10

(A total of 24 tests)

---

and fit to a seven-point incremental exponential function. The crack growth rate data correlated well when plotted as a function of cyclic stress intensity (delta K). This is an indication that LEFM may indeed be applicable to this composite system. All of the crack growth data are tabulated in the Appendix C.

The stress intensity at fracture for all specimens is shown in Table 9. Some of the specimens were failed by increasing the load at the end of the test. The K_{max} measured for transverse specimens varies little (from 13.9 to 19.1 MPa√m) over the temperature range from 26°C to 649°C. It is highest at 316°C; an anomaly which is also evident in the crack growth data. The longitudinal data showed a greater degree of variation. At room temperature two specimens produced K_{max} greater than 150 MPa√m, but the remaining three averaged 109 MPa√m. Of 11 specimens tested at 649°C, one measured 121.3; another 110.3; four others averaged 102; and the remaining five were all lower than 75, averaging 70 MPa√m. There is no discernable pattern to this scatter in terms of specimen origin. Four of five of the lowest K_{max} valves were produced in the low frequency and dwell tests.

Table 9.
Stress intensity of fracture for FCGR tests.

Spec No.	Temp--°C	R-ratio	Freq--cpm	Orientation --deg	A mm	Pmax--kg	Kmax-- MPa√m
Transverse							
A62-2	26	0.1	200	90	3.56	685	13.9
A55-4	26	0.1	200	90	0.51	703	----*
A61-2	316	0.1	200	90	17.53	223	17.1
A58-2	316	0.1	200	90	14.99	291	19.1
A55-2	649	0.1	200	90	18.57	188	16.1
A62-4	649	0.1	200	90	20.83	147	15.4
Longitudinal							
***A98-6	26	0.1	200	0	7.53	4295	157.7
A100-6	26	0.1	200	0	12.70	2163	107.6
A101-6	26	0.5	200	0	10.26	2439	104.7
A105-6	26	0.5	200	0	14.26	2924	150.7
A103-1	26	0.8	200	0	8.38	3080	114.0
***A98-1	316	0.1	200	0	16.94	1994	150.1
A104-6	316	0.1	200	0	13.97	2145	111.6
A97-6	649	0.1	200	0	16.26	2088	121.3
**A99-1	649	0.1	200	0	17.22	1298	100.2
A104-1	649	0.5	200	0	13.72	2041	104.4
A101-1	649	0.5	200	0	7.21	2943	100.0
A97-1	649	0.8	200	0	8.56	2143	73.1
A100-1	649	0.8	200	0	13.21	2133	110.3
A99-6	649	0.1	2	0	7.39	2245	72.6
A103-6	649	0.1	2	0	15.75	1767	103.5
A105-1	649	0.1	2	0	12.70	1482	64.6
A102-1	649	0.1	5 min. dwell	0	7.62	2041	67.3
A102-6	649	0.1	5 min. dwell	0	10.92	1483	71.1

*Specimen A55-4 failed away from the notch
**No monolithic edge
***Undersize in thickness

4.4.1 Effect of Temperature and Orientation on FCGR

As noted previously and shown in Figure 47, the transverse fatigue crack growth was lowest at 316°C. The room temperature and 649°C data are very similar. The brittle nature of Ti-24Al-11Nb at 26°C is probably the reason for the lack of toughness and rapid growth at that temperature. At 316°C the matrix has improved ductility, but the deleterious effects of elevated temperature on behavior are not yet active.

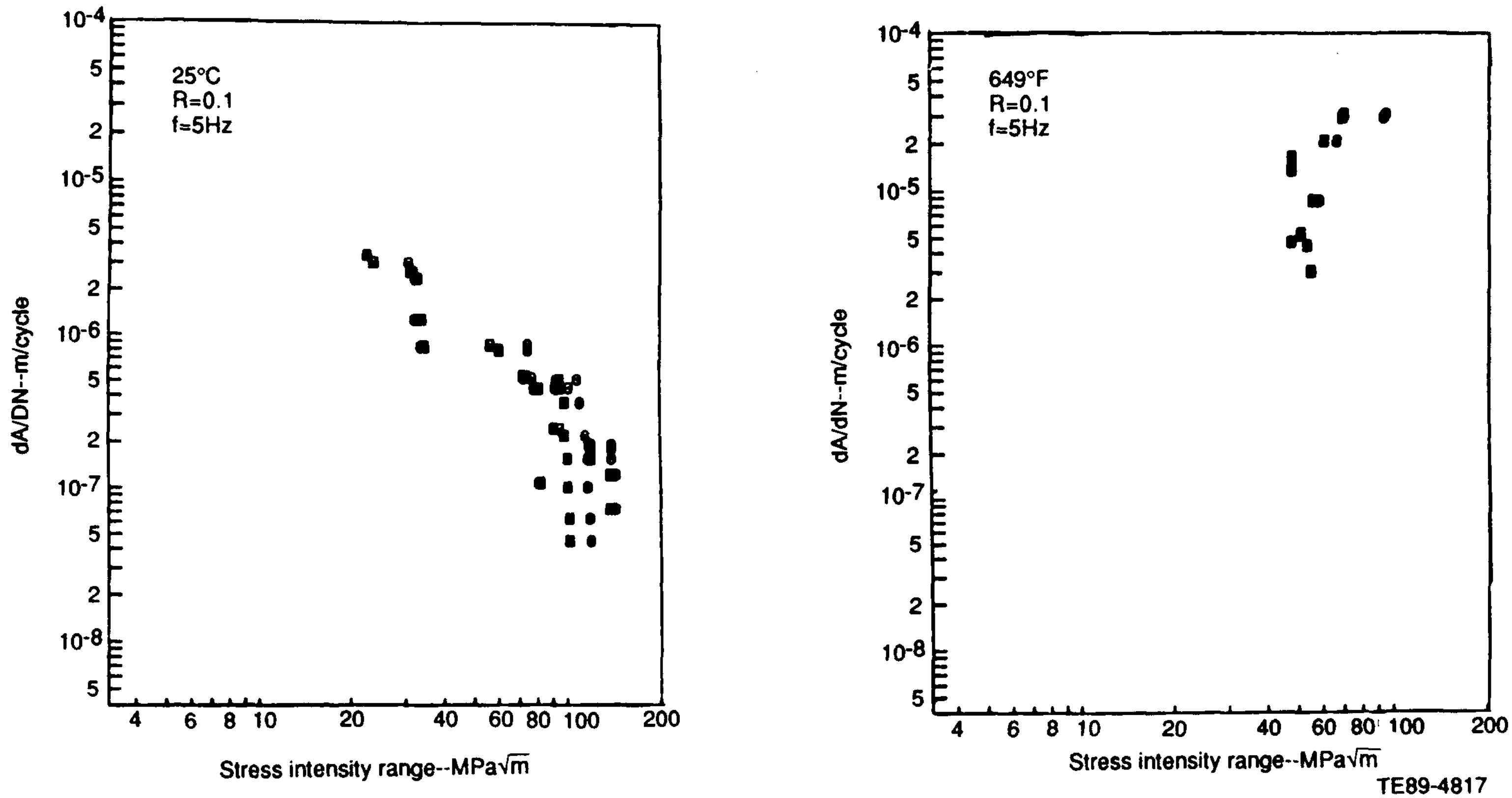


Figure 46. Bolt hole FCGR tests performed on SCS-6/Ti_3Al to develop test procedure.

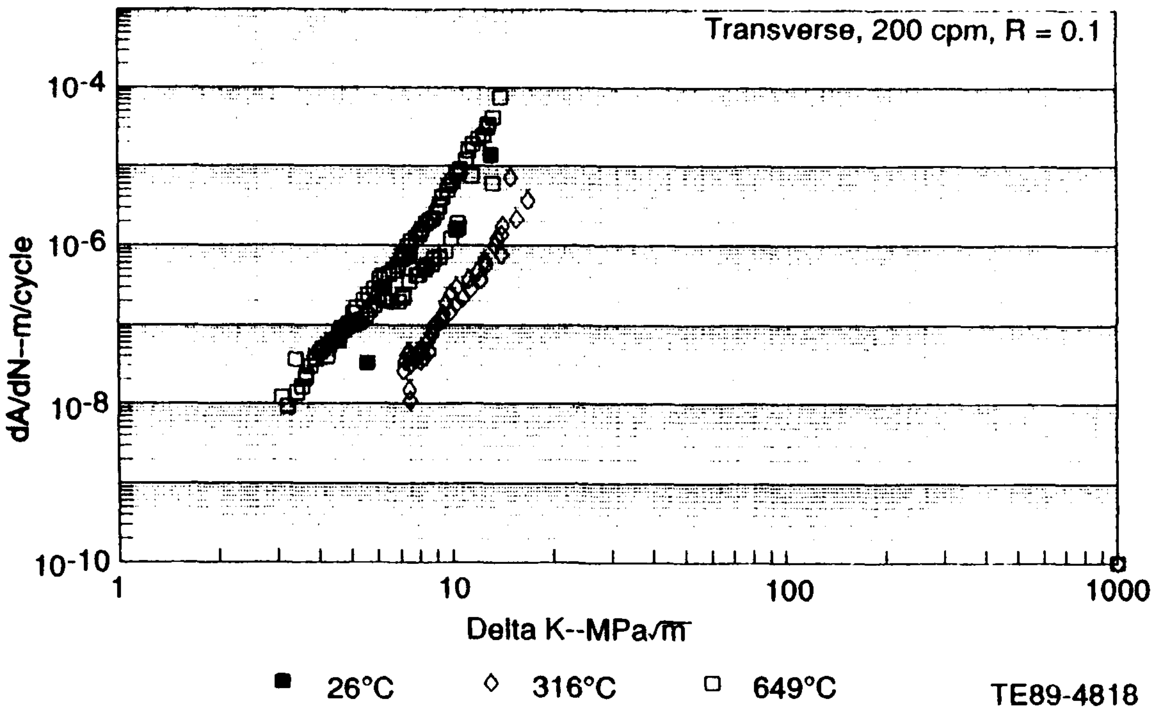


Figure 47. Fatigue crack growth rate as a function of stress intensity for transverse SCS-6/Ti_3Al.

Crack growth in the transverse orientation is significantly more rapid than in the longitudinal orientation over the entire range of temperature. Figure 48 shows longitudinal fatigue crack growth at 26, 316, and 649°C as well as curves representing the transverse data. It is evident that the transverse crack growth rate exceeds the longitudinal by five orders of magnitude.

The temperature dependence of the longitudinal FCG data is more typical than that of the transverse. The crack growth rate is lowest at 26°C and increases by an order of magnitude at 316°C and again at 649°C. In fact, it is extremely difficult to grow a crack across fibers at room temperature in this material system. The growth rate never was higher than 10^{-8} m/cycle and a successful test was only achieved by precracking at elevated temperature. Under normal cycling at 26°C a crack will grow a short distance and stop and will not proceed until the stress range is increased. It is hypothesized that the crack proceeds in the matrix around the fibers and that these unbroken fibers bridge the crack tip and lower the stress there. This would explain the crack jumping forward with a higher applied stress. As each row of fibers is fractured, the crack moves ahead and is stopped at the next row.

At elevated temperatures, however, longitudinal crack growth behavior is similar to that of monolithic materials. Figure 49 shows a typical fracture at 649°C. The fiber "pull-out" is evidence of fiber fracture out of the plane of the matrix crack, and there is considerable oxidation on the fracture even at a frequency of 200 cpm.

4.4.2 Effect of R-Ratio on FCGR

Figures 50 and 51 illustrate the effect of R-ratio on crack growth rate of longitudinal specimens at 26°C and 649°C, respectively. There is definitely

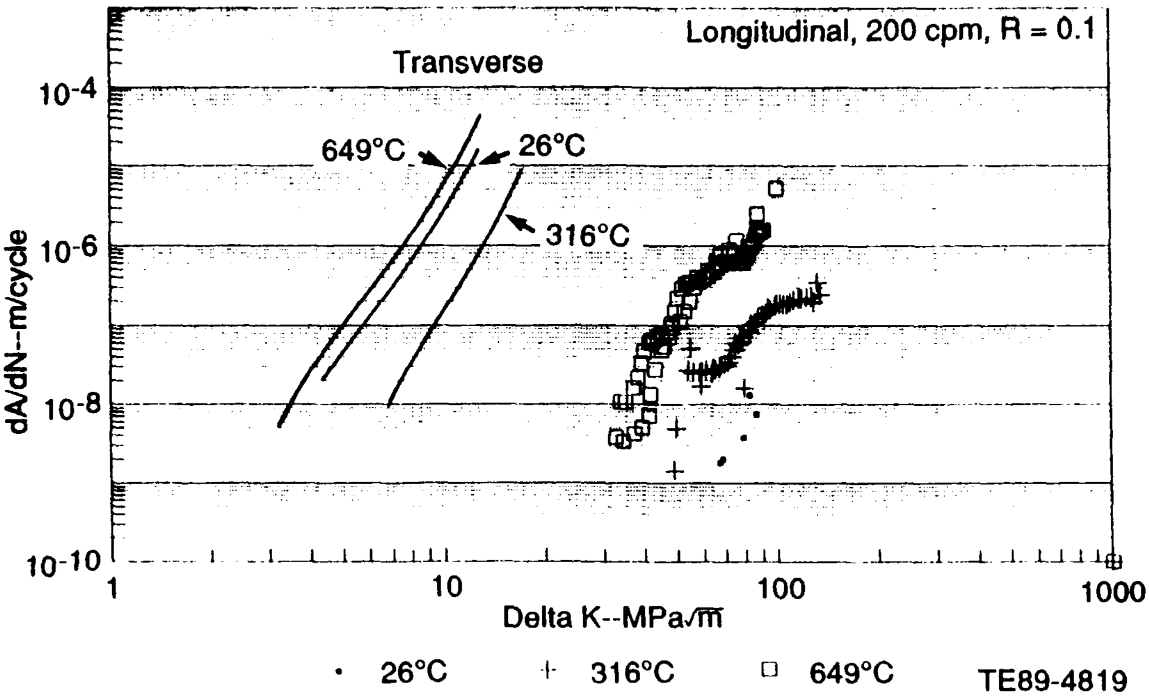


Figure 48. Fatigue crack growth rate of longitudinal SCS-6/Ti_3Al compared with that of transverse composite.

an increase in crack growth rate with mean stress at both temperatures. It proved impossible to test specimens at R of 0.8 at 26°C. The specimens simply pulled in two. Figure 52 shows the correlation of fatigue crack growth rate with maximum stress intensity at 26°C. It is evident that the data from both R-ratios falls on the same curve when plotted versus maximum stress intensity. This result is expected since maximum strain was found to correlate fatigue initiation life at room temperature. Maximum stress intensity does not correlate crack growth rate at different R-ratios at 649°C.

4.4.3 Effect of Frequency on FCGR

The effect of frequency and, particularly, dwell at maximum stress is illustrated on Figure 53. A decrease in frequency from 200 cpm to 2 cpm shows only a slight effect at the highest stress intensity. However, the imposition of a 5-minute dwell at maximum stress on the cycle results in more than an order of magnitude increase in the crack growth rate. The fracture surface of the specimens subject to the dwell cycle are more heavily oxidized than the higher frequency tests (Figure 54), but there is no other notable difference in the fracture appearance.

4.5 THERMAL MECHANICAL FATIGUE BEHAVIOR

The test matrix for thermal mechanical fatigue (TMF) testing of SCS-6/Ti_3Al for the Task IV effort is given in Table 10. Also, 11 out-of-phase TMF tests cycled between 316°C and 760°C were conducted as part of the Task VI program expansion. Five tests were performed using longitudinal specimens and three of each cross-ply configuration, $[0\ deg/90\ deg]_s$ and $[0\ deg/\pm45\ deg/90\ deg]_s$. In these 36 tests, the effects of a combination of a thermal and mechanical strain cycle applied to the composite were evaluated. Such factors as R-ratio,

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Figure 49. Fracture of a 649°C longitudinal fatigue crack growth specimen. The fracture surface is oxidized (B) and shows extensive fiber pullout.

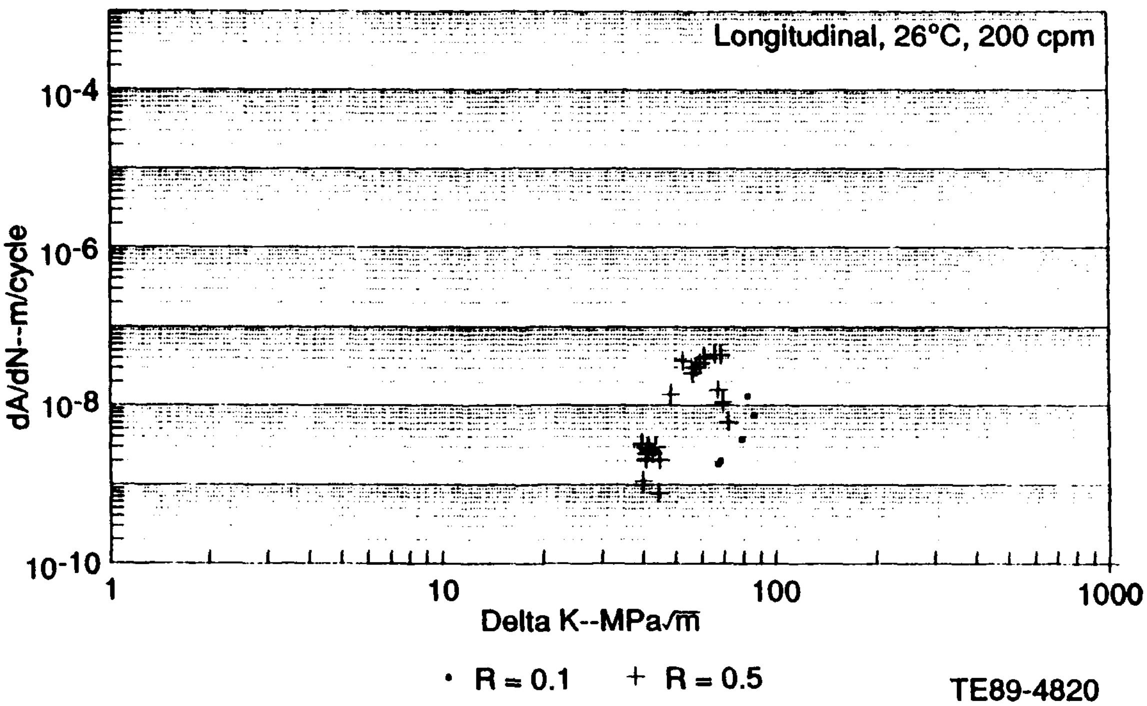

Figure 50. Fatigue crack growth rate of longitudinal SCS-6/Ti_3Al at room temperature showing the variations with R-ratio.

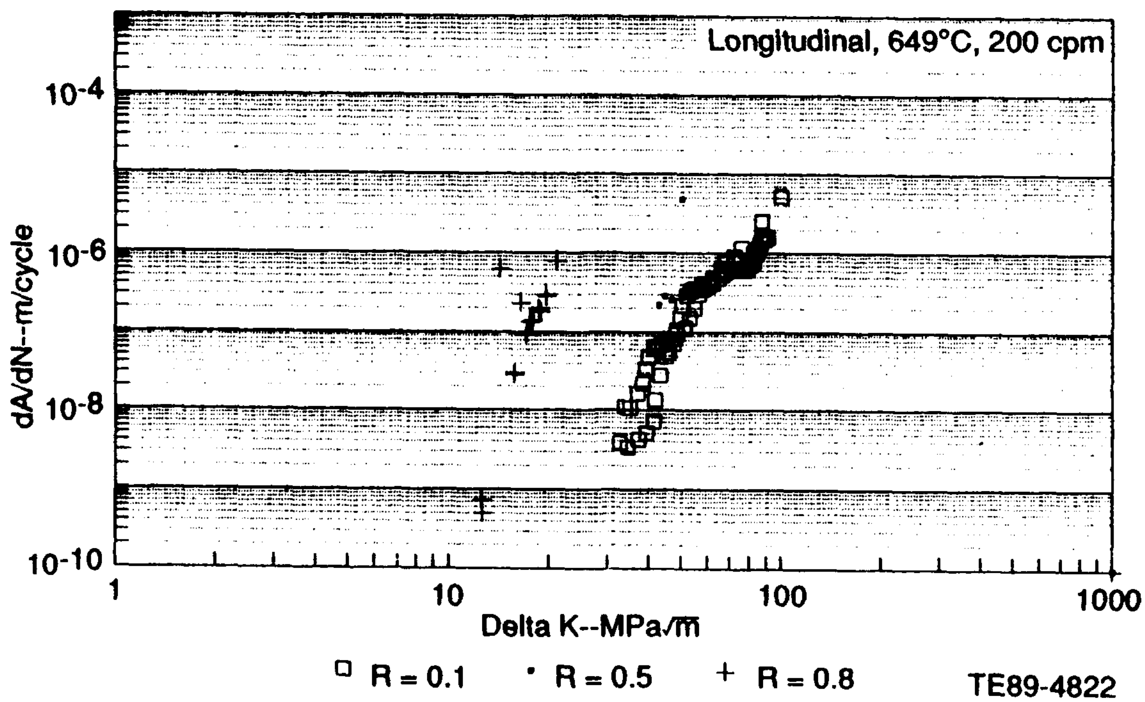

Figure 51. Fatigue crack growth of longitudinal SCS-6/Ti_3Al at 649°C showing R-ratio effect.

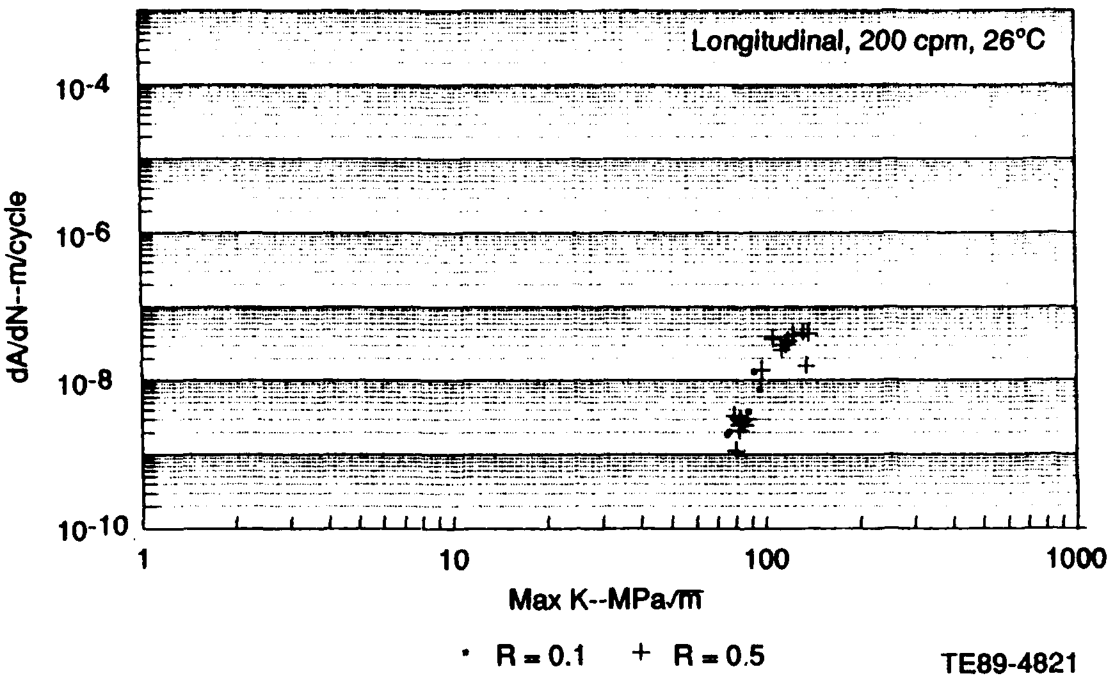

Figure 52. Fatigue crack growth versus maximum stress intensity for R = 0.1 and 0.5 longitudinal specimens at room temperature.

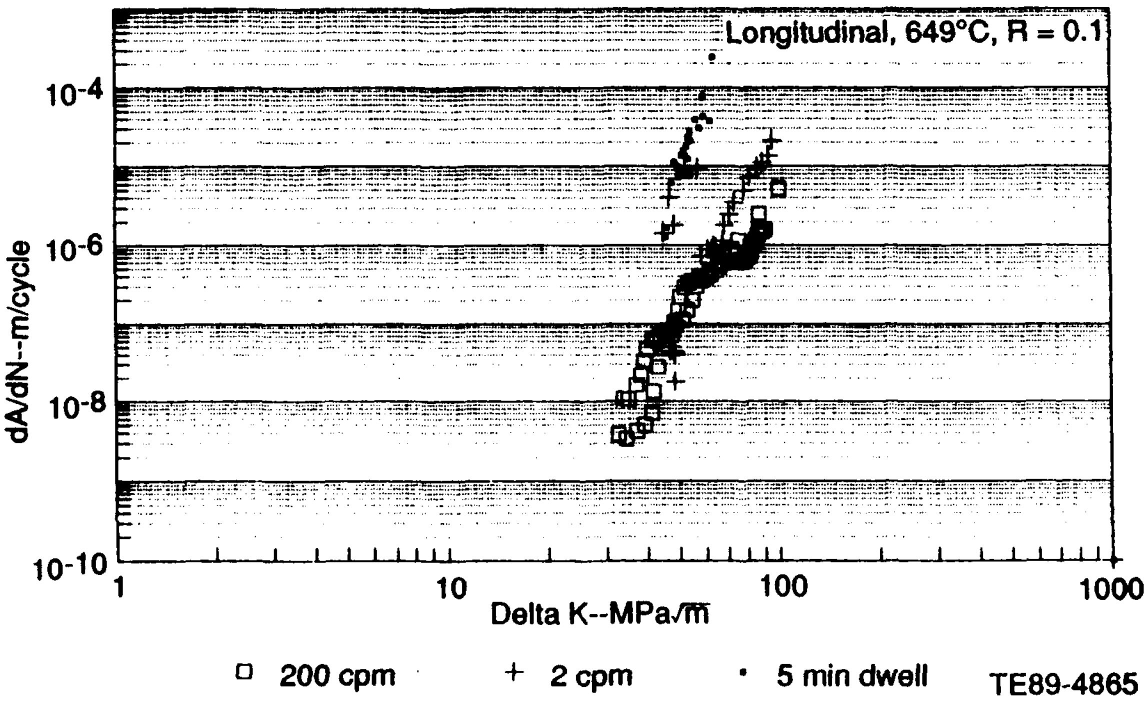

Figure 53. Effect of frequency and dwell on the FCGR of longitudinal SCS-6/Ti_3Al at 649°C.

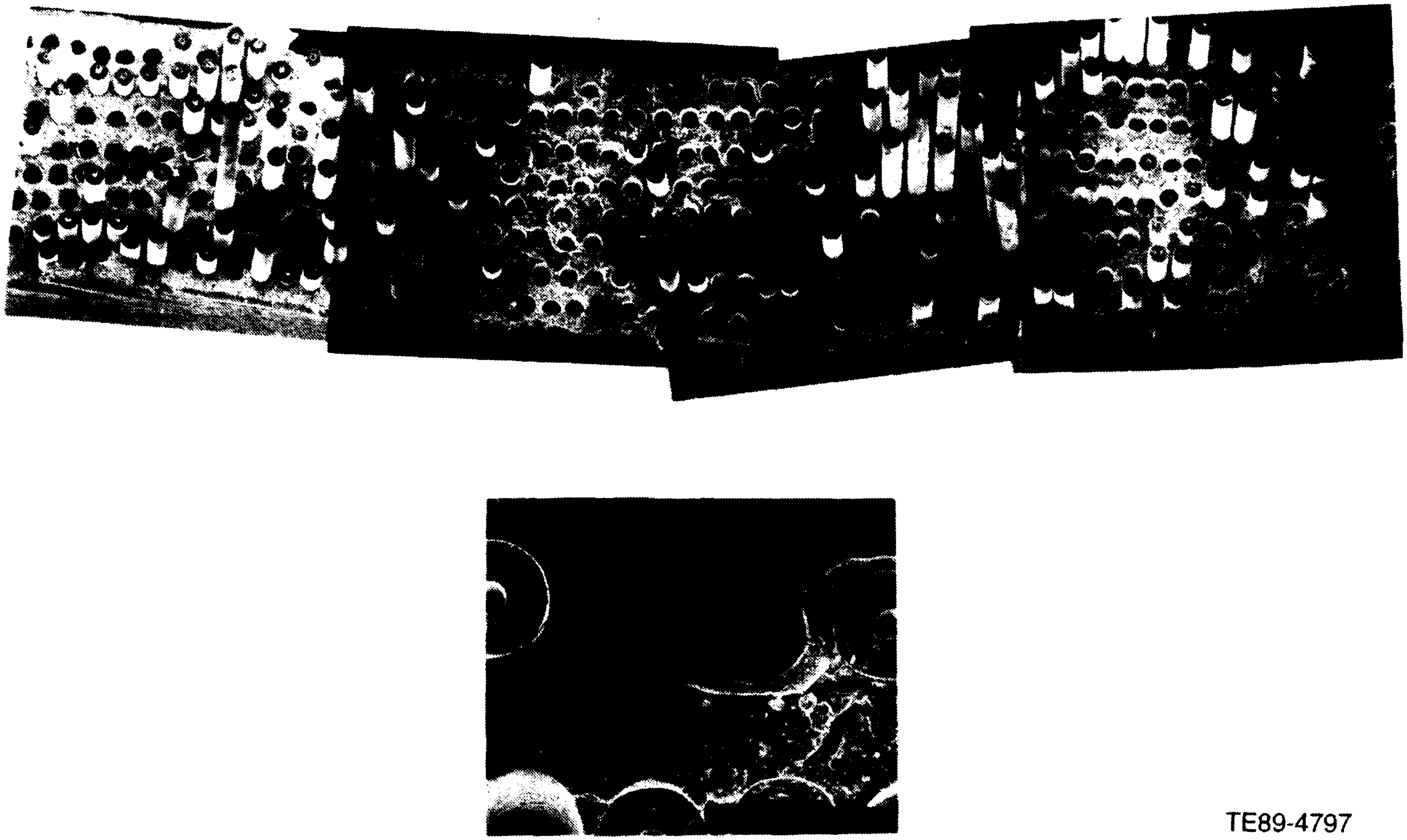

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Figure 54. Fracture of a 649°C longitudinal FCG specimen tested with a 5 minute hold at the peak stress in each cycle. Surface is more severely oxidized than that of higher frequency tests (B).

Table 10.
Thermal mechanical fatigue test matrix.

Number of tests/condition

Temperature range--°C	In-phase	Out-of-phase	R-ratio
25-650	5	5	0.10
25-650	5	-	0.50
316-650	5	5	0.10

*Longitudinal, 0.67 cpm

(A total of 25 tests)

temperature range, and phasing were also considered. Tabulated results of each test are listed in Appendix D.

The tests were performed at Materials Behavior Research Corporation. In each test a specimen is subject to a thermal cycle until a stable cycle is achieved. The strain generated from expansion and contraction of the specimen with temperature change is measured and becomes the null point from which the mechanical strain is applied. All the tests were performed with a 90-sec cycle. The specimens were heated by induction and no active cooling was employed.

The fracture surfaces of the TMF tested to 760°C were highly oxidized. This oxidation made it impossible to determine the origin of the failures. There were, however, many small matrix cracks throughout the gage of the failed specimens. The presence of these cracks and the irregular plane of the fracture surface indicate that failure was probably caused by a linking of several of these matrix cracks.

4.5.1 Effects of Temperature Range on TMF

Three temperature ranges were tested: 316°C to 649°C, 93°C to 649°C, and 316°C to 760°C. (The last temperature cycle was only out of phase.) Figure 55 shows a plot of the lives of all the out-of-phase TMF specimens versus the applied mechanical strain range, and Figure 56 shows the in-phase TMF lines.

From these data it is evident that a greater temperature range has a deleterious effect on the lives of TMF specimens cycled out-of-phase. An increase in temperature span from 333°C to 556°C reduced the out-of-phase TMF life to one-third of its original value. This result is not surprising because in the out-of-phase cycle the maximum residual stress due to thermal mismatch is added to the maximum applied stress, making this cycle the most severe. Any increase in the temperature range will also increase the thermal mismatch stress. Maximum temperature in the cycle also plays a role in the out-of-phase TMF life. Comparison of the lives of those specimens cycled from 93°C to 650°C to those cycled from 315°C to 760°C indicates that the higher maximum temperature has a deleterious effect on life even though the temperature range of the latter specimens is smaller than that experienced by the former.

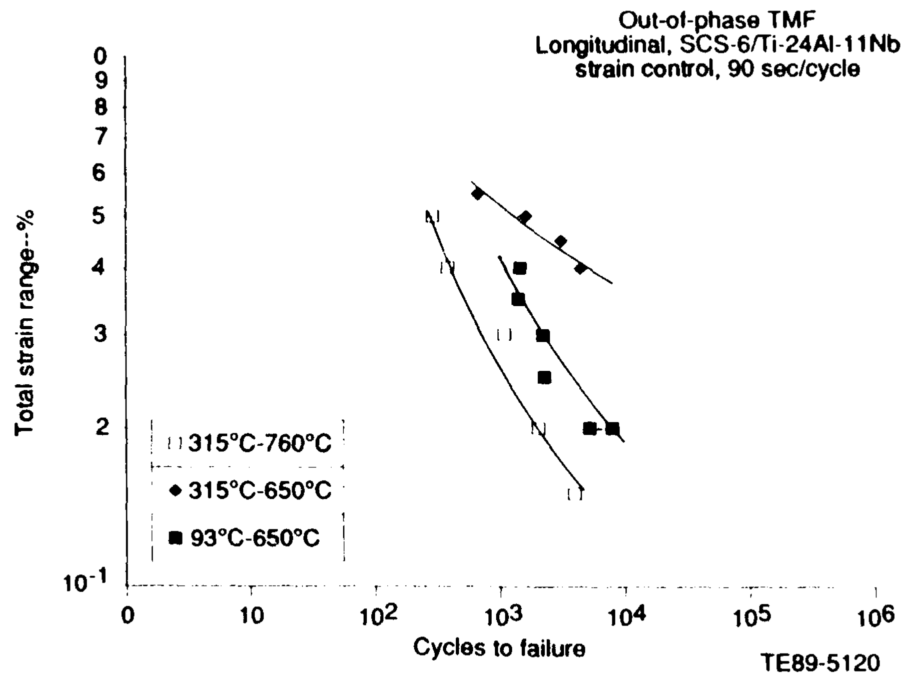


Figure 55. Mechanically applied strain as a function of life for thermal mechanical fatigue tests of SCS-6/Ti-24Al-11Nb composite.

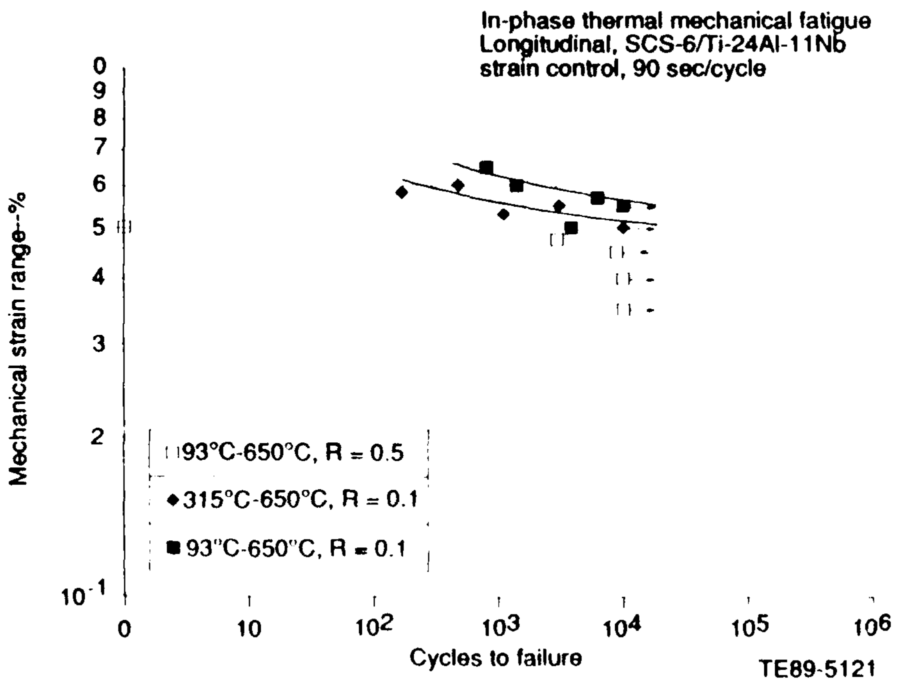


Figure 56. Mechanically applied strain as a function of life for in-phase TMF tests of SCS-6/Ti-24Al-11Nb composite.

The in-phase TMF data show little effect of temperature range. The greater temperature range specimens have slightly better lives than those cycled from 316°C to 649°C. This could be due to the opposite of the effect described previously. The mismatch stresses are lowest at the maximum applied stress in an in-phase cycle, and a greater temperature range will be less severe than a smaller one.

Figures 57 and 58 illustrate the fracture surfaces of typical out-of-phase and in-phase test specimens cycled to a maximum temperature of 640°C, respectively. Both types of cycle produced specimens with clear initiation sites at the gage surfaces. All specimens showed multiple initiations primarily at corners. The initiation and growth areas showed heavy oxidation, but nothing as severe as that observed in the TMF specimens tested in Task VI to 760°C, shown in Figure 59. Very little evidence of general cracking throughout the gage length was observed at the lower maximum temperature of 649°C.

4.5.2 Effect of Lay-up on TMF

Three specimens in each cross ply lay-up were also tested in out-of-phase thermal mechanical fatigue from 316°C to 760°C. A plot of the data is shown in Figure 60. The cross ply lives fell slightly short of those measured for the unidirectional composite, but it is difficult to assess the significance of their relationship with such a small quantity of data.

4.5.3 Effect of Phasing on TMF

As previously discussed, the effect of phasing between temperature and mechanical strain is due to the thermal mismatch stresses created in the fiber and matrix of the composite. Isothermal fatigue tests performed in Task II and Task VI gave indications that the matrix strain-life behavior controls the strain-life behavior of the composite. Thus, the strain generated in the matrix due to the phasing of the TMF cycle should determine the TMF life of a specimen. Figure 61 illustrates the effects of both out-of-phase and in-phase TMF cycles on the constituents of the composite. During an out-of-phase cycle, the thermal mismatch strain cycle, of the matrix is in phase with the applied strain and thus these effects are additive. However, these strain cycles are 180 deg out of phase during an in-phase test; so the actual strain on the matrix is less severe while the fiber undergoes a more severe cycle.

If this hypothesis is correct, then two results will follow: (1) the lives of in-phase TMF specimens will be longer at the same applied strain range than isothermal LCF specimens and (2) the lives of out-of-phase TMF specimens should coincide with those of isothermal LCF specimens when total matrix strain is plotted. Figure 62 shows the in-phase data plotted with the 649°C LCF data, and there is an improvement in fatigue limit for the TMF specimens over the LCF. The improvement in life is not as great as might be expected. Figures 63 and 64 are similar plots of the out-of-phase TMF lives with the isothermal LCF data. The strain range plotted for the TMF data is the total matrix strain range based on the component of the thermal mismatch strain borne by the matrix. The equation by which this mismatch strain is calculated is as follows:

$$\varepsilon_m = \frac{\Delta\alpha \Delta T E_f V_f}{(V_f E_f + E_m - V_f E_m)}$$

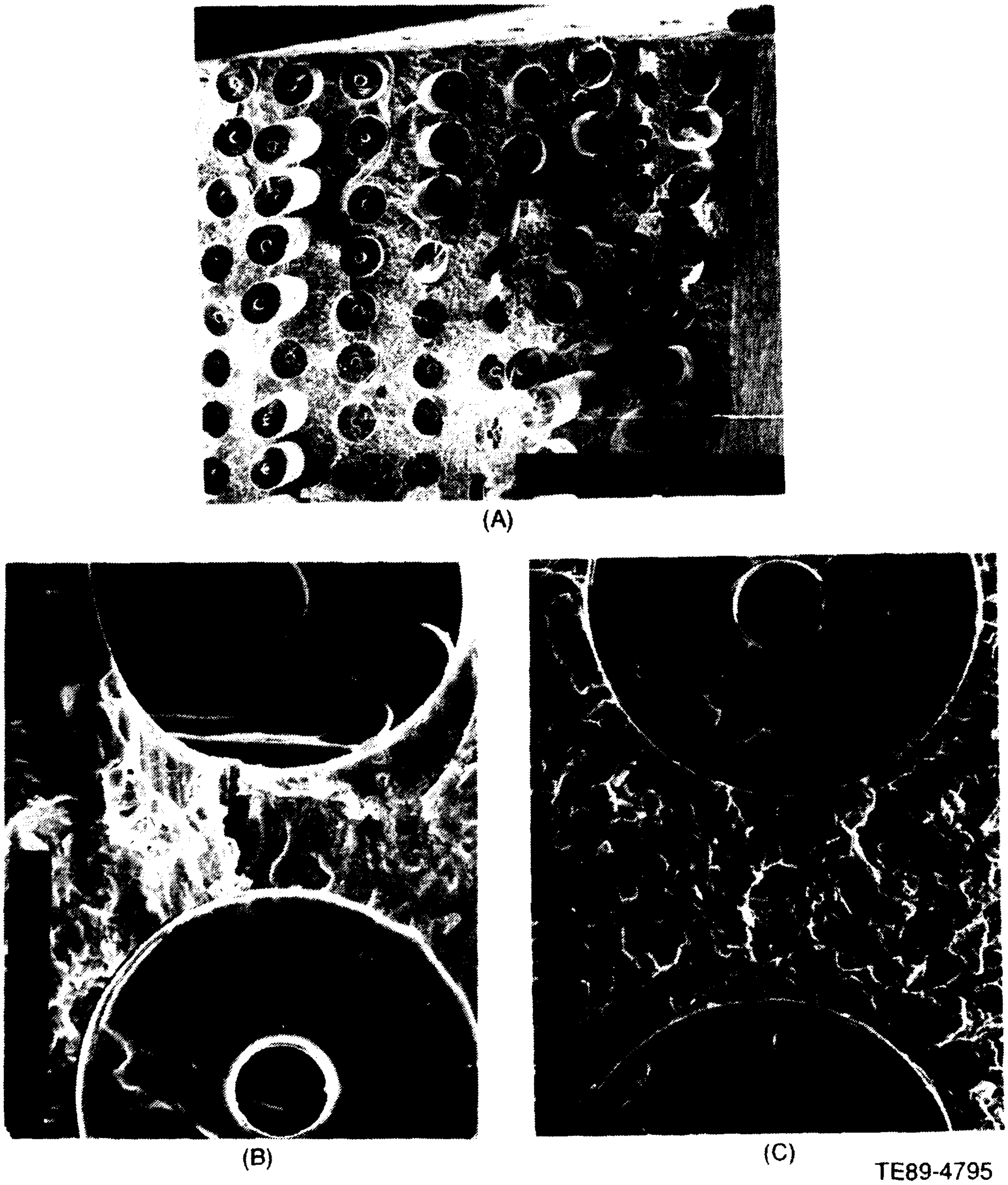
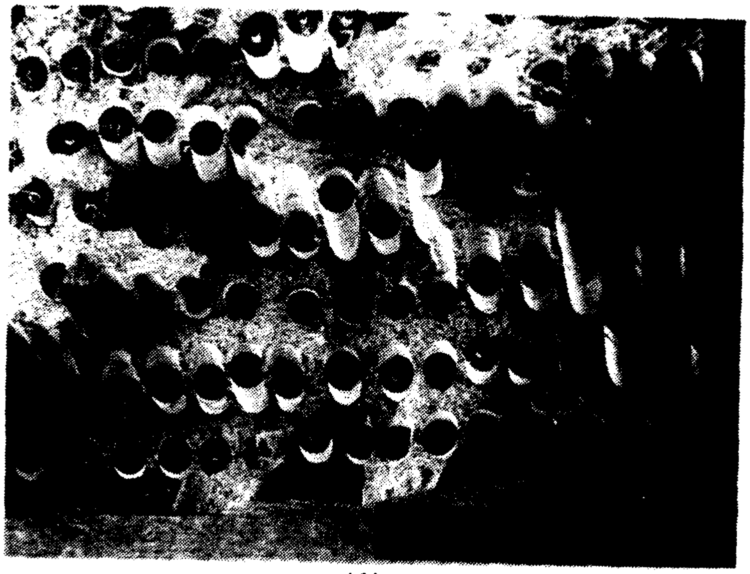


Figure 57. Fracture surface of SCS-6/Ti_3Al TMF specimen cycled out-of-phase from 93°C to 650°C. Heavily oxidized initiation areas occur at the specimen surface (A) and (B), primarily at corners and along the face. The overload fracture is relatively flat and shows little fiber pullout (C).



(A)

(B)

(C)

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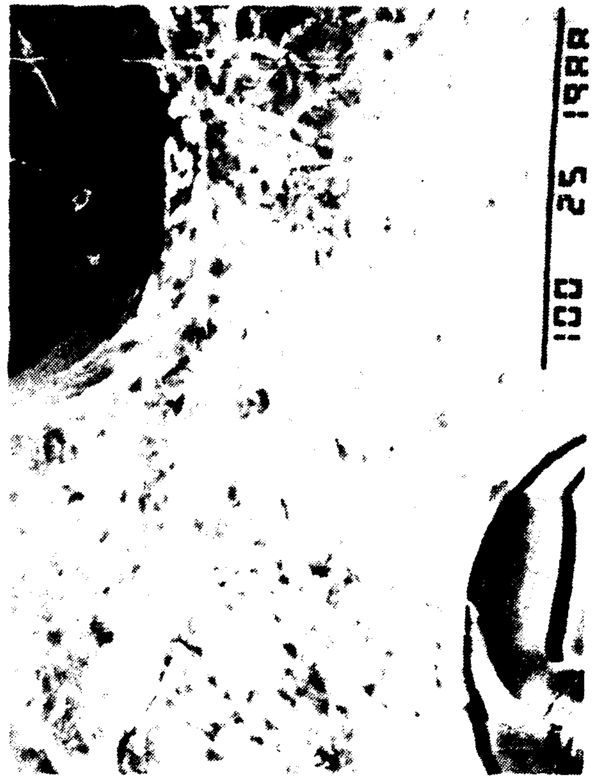
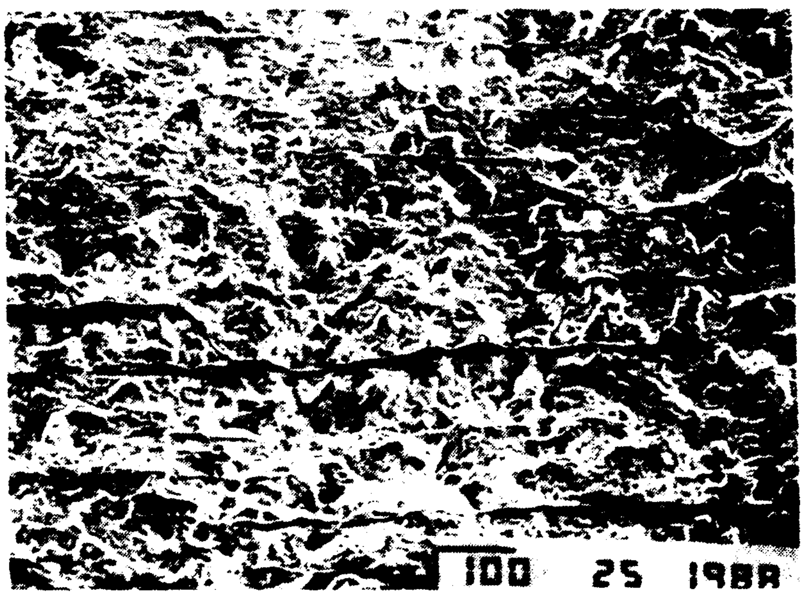
Figure 58. Fracture of an in-phase SCS-6/Ti_3Al TMF specimen tested from 93°C to 650°C. Multiple initiations occur at the surface of the gage (A). The fatigue fracture is oxidized (B), but overload shows a more ductile fracture (C).

(A)



(B)



(C)

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Figure 59. Typical thermal fatigue fracture of SCS-6/Ti-24Al-11Nb composite: (A) fracture surface (note fracture on several horizontal planes), (B) oxidized matrix fracture, and (C) matrix cracks noted throughout gage area.

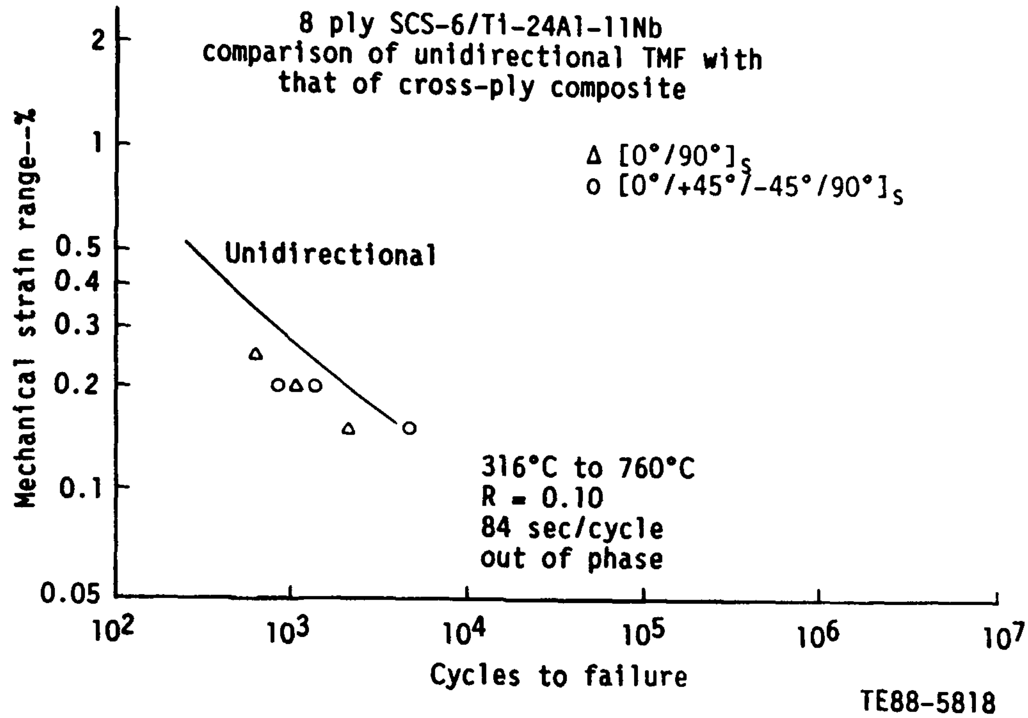

Figure 60. Mechanical strain range as a function of cyclic life for cross-ply (points) and unidirectionally reinforced SCS-6/Ti-24Al-11Nb composite.

where $\Delta\alpha$ is the difference in thermal expansion between fiber and matrix; ΔT is the temperature range; E_f and E_m are the modulus of fiber and matrix, respectively; and V_f is the volume fraction of fiber in the composite. The strain due to thermal mismatch was 0.22% for the 93°C to 649°C cycle and 0.13% for the 316°C to 649°C cycle, and 0.16% for 316°C to 760°C cycle. In Figure 65 the TMF data fall on the LCF curve within the scatter of the LCF data. This indicates that total matrix strain does control the TMF life in an out-of-phase cycle. In Figure 64 the 760°C maximum temperature TMF data fall below the 760°C isothermal fatigue data. This is another indication that the higher maximum temperature plays a significant role in TMF life.

4.5.4 Effect of R-Ratio on TMF

Five specimens were tested at an R-ratio of 0.5 and with an in-phase cycle from 93°C to 649°C. The data are illustrated in Figure 55. The higher R-ratio did have a detrimental effect on the life of the composite specimens when compared with the R of 0.1 data for the same cycle, but the effect was less severe than expected. However, the most interesting result of the combination of a high R-ratio with an in-phase cycle was the lack of fatigue failure. Of these five specimens, only one failed after a substantial number of fatigue cycles. Three specimens did not fail in 10,000 cycles, and a fourth failed on the second cycle. The total strain to which these specimens were subjected was high, from 0.70% to 1.0% maximum strain. The only fatigue failure was measured on the specimen cycled from 0.475% to 0.95% strain.

It is probable that applied strain range was offset by the thermal mismatch strain with the result being that the matrix was subject to a strain cycle

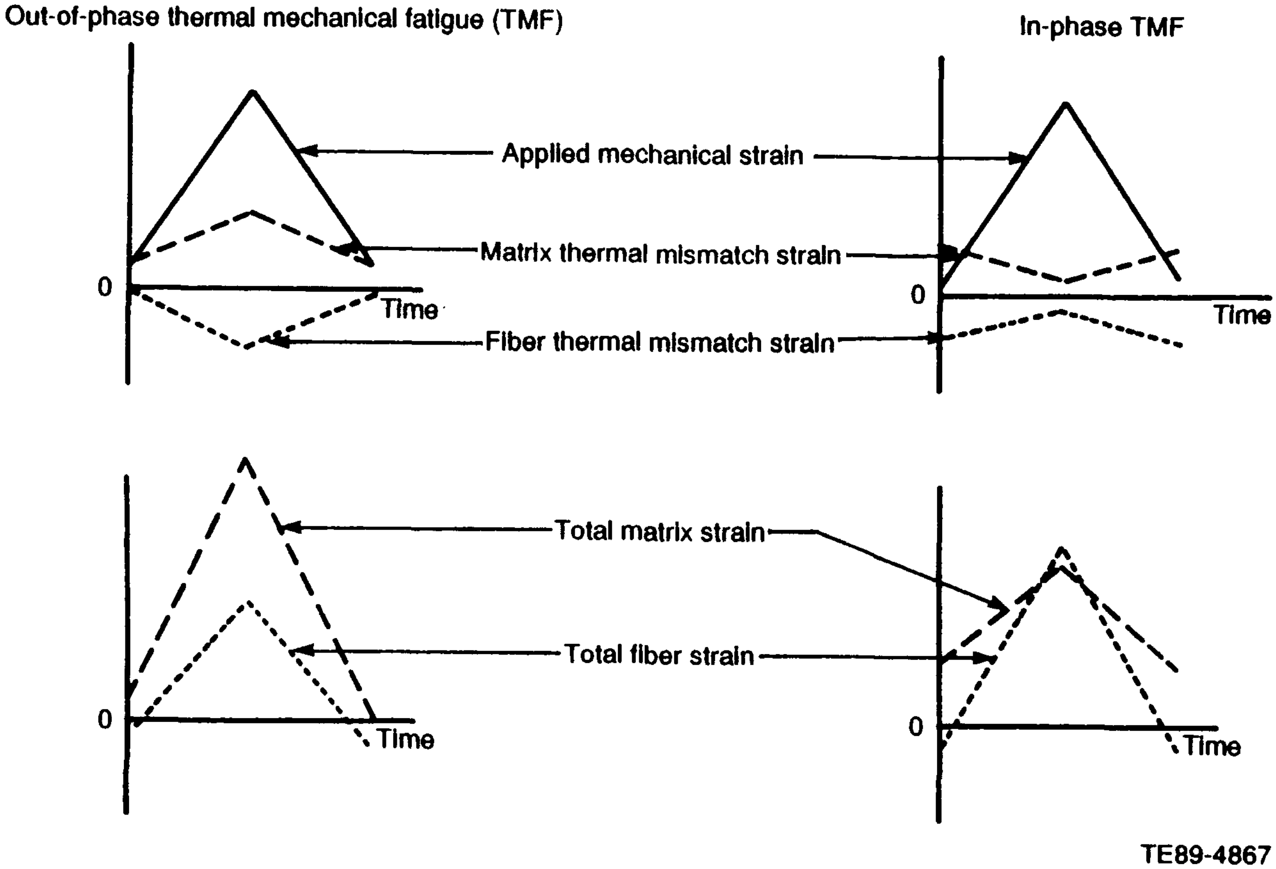

Figure 61. Schematic representation of the strain produced in fiber and matrix by in-phase and out-of-phase TMF cycles.

below its fatigue limit. Failure may only occur when fiber damage is severe and not due to matrix fatigue at all. There was evidence of fiber damage at these high maximum strains. Figure 65 shows the initial cycles of specimen 60-1. This is typical of observations in the other four specimens. In the first cycle several incidences of sharp drops in load occurred. These are not due to extensometer slip or any other testing artifact, but appear to indicate local fiber breakage. One percent strain is near the limit of what the SCS-6 fiber can withstand, and it is possible that these load drops are failures of one or two weaker fibers. Nondestructive evaluation (NDE) of the unfailed specimens did not reveal these broken fibers, however. Fatigue failure may only occur in these conditions if a sufficient amount of local damage is done in the first cycles from which to propagate a fatigue crack.

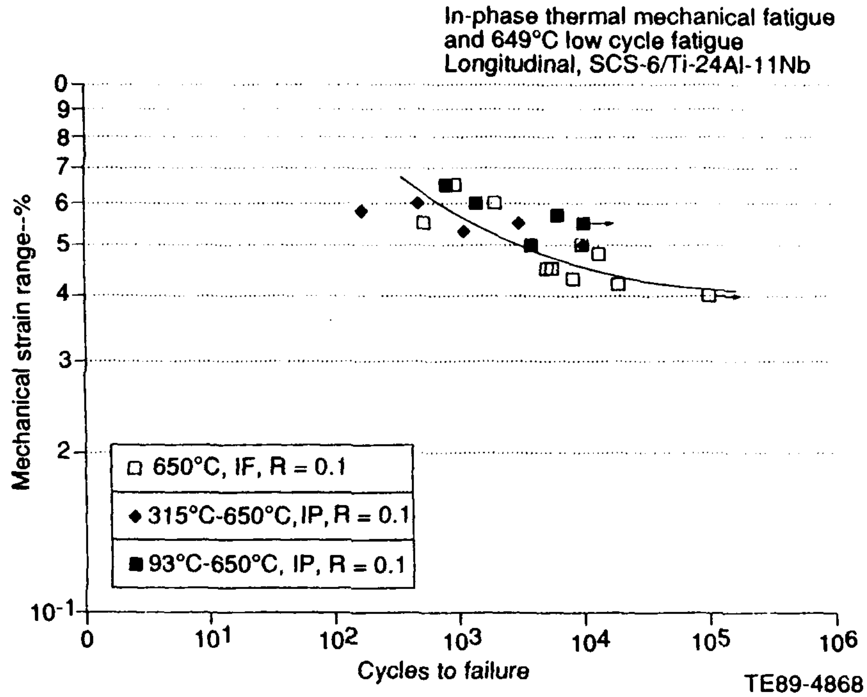

Figure 62. Applied strain range as a function of life for both in-phase TMF and isothermal LCF specimens.

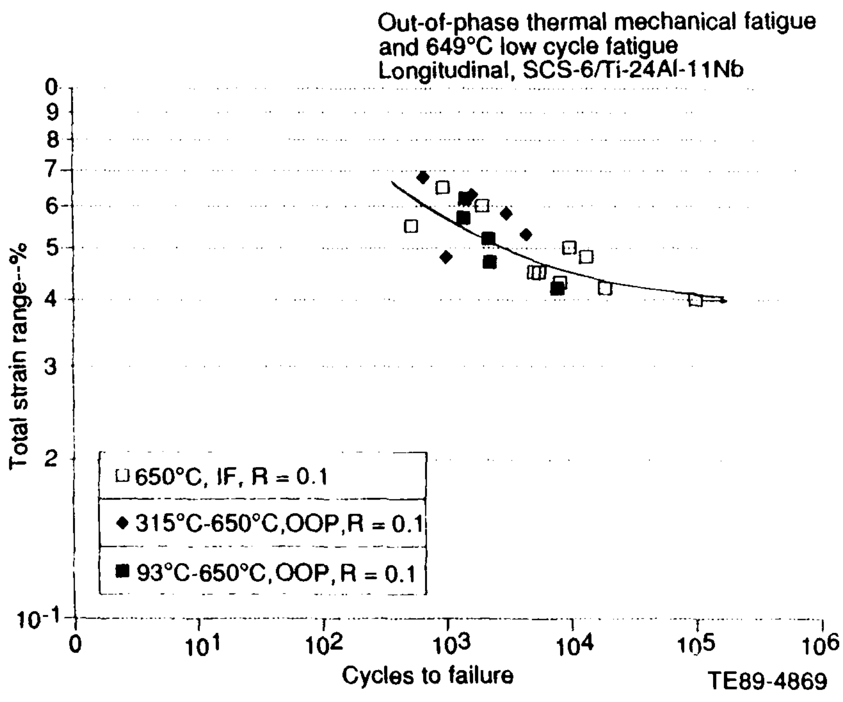

Figure 63. Total matrix strain as a function of cycles to failure for out-of-phase TMF plotted with isothermal LCF at 649°C.

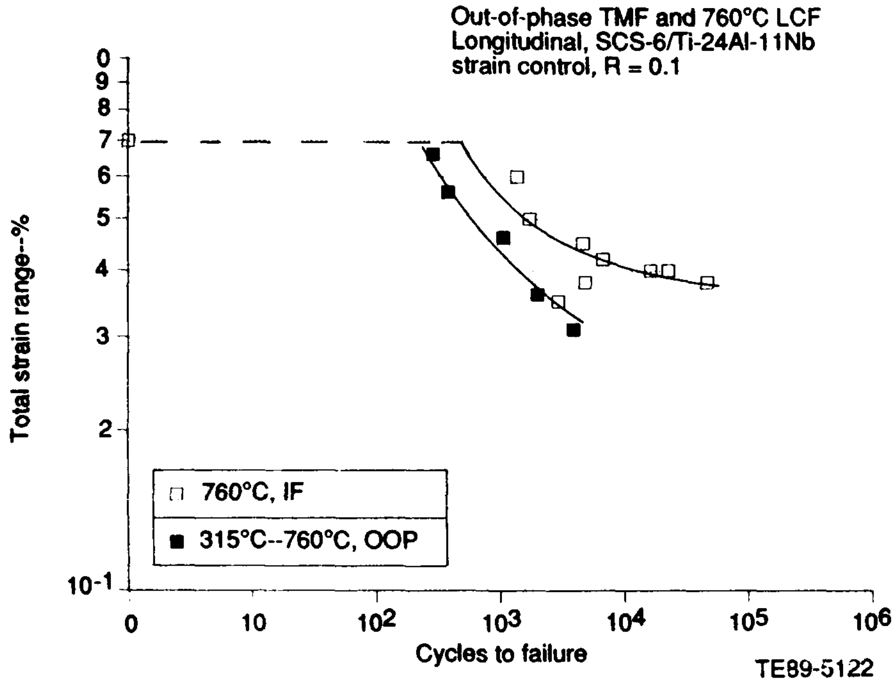

Figure 64. Total matrix strain as a function of cycles to failure for out-of-phase TMF plotted with isothermal LCF at 760°C.

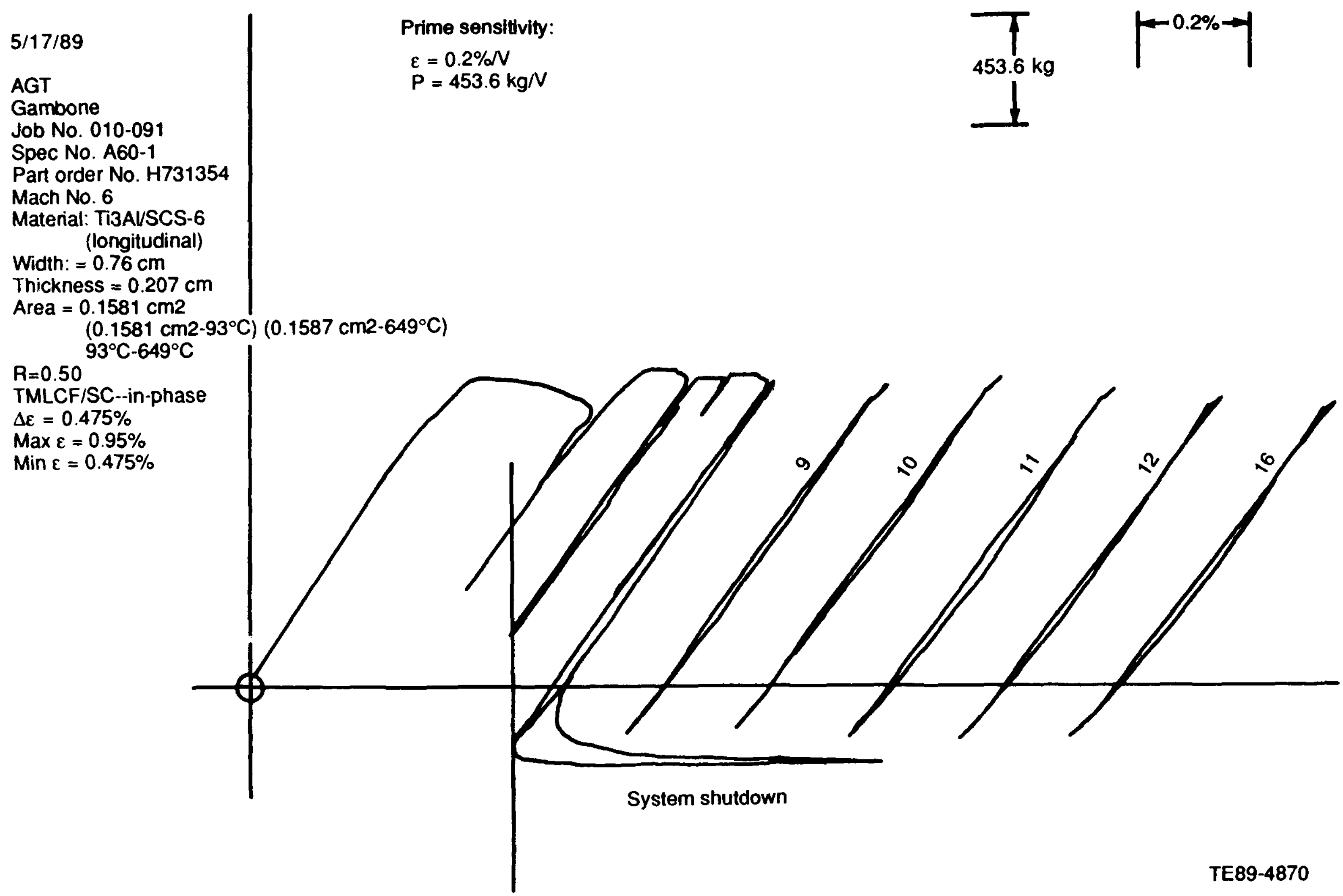

Figure 65. Typical hysteresis loops for the startup of an in-phase, R = 0.5 TMF test. Note the load drops that occur in the first cycle.

V. CONCLUSIONS

The following conclusions may be drawn from the preceding discussion:

- o Rule-of-mixtures tensile strength has been achieved in the SCS-6/Ti_3Al composite system.
- o Transverse stress-rupture properties have been modeled empirically in the temperature range of interest.
- o Isothermal and thermal mechanical fatigue properties have been measured to 760°C.
- o Matrix strain-life behavior controls the fatigue and thermal mechanical fatigue life of this composite system.
- o Fatigue initiation life decreases at temperatures above 316°C for longitudinally oriented material, but improves for specimens oriented at 45 deg or transverse to the load axis.
- o The LCF behavior of longitudinal and 45 deg specimens is equivalent at 649°C.
- o Longitudinal composite shows a notch sensitivity at room and elevated temperatures on the same order of a cast monolithic material (Q = 0.2 at 26°C and 0.15 at 649°C).
- o Transverse composite demonstrates no notch sensitivity.
- o At room temperature, longitudinal fatigue tests performed at different R-ratios correlate with maximum strain.
- o At 649°C, fatigue life does not correlate with maximum strain or strain range. As mean strain increases, so does the fatigue limit.
- o Frequency has no discernible effect on the fatigue initiation life of SCS-6/Ti_3Al composite at room temperature.
- o Higher frequency improves the elevated temperature fatigue life of longitudinal SCS-6/Ti-24Al-11Nb composite.
- o Linear elastic fracture mechanics correlates the fatigue crack growth behavior of SCS-6/Ti_3Al composite.
- o Longitudinal composite demonstrates fracture toughness from 150 to 110 $MPa\sqrt{m}$ at room temperature and from 120 to 70 $MPa\sqrt{m}$ at 649°C.
- o Transverse composite shows the lowest crack growth rate and highest fracture toughness at 316°C when compared to 26°C and 649°C.
- o Cracks do not readily grow across fibers at room temperature.
- o Cracks through transverse specimens propagate at a rate five orders of magnitude greater than those in longitudinal specimens.
- o Maximum stress intensity correlates fatigue crack growth of specimens of different R-ratio at 26°C.
- o The fatigue crack growth rate increases in longitudinal specimens at 649°C with a decrease in frequency from 2 cpm to a 5-minute dwell at maximum stress by more than an order of magnitude.
- o Out-of-phase TMF life is reduced with an increase in temperature range while in-phase life is increased.
- o A higher maximum temperature in an out-of-phase cycle, particularly 760°C compared to 649°C, decreases TFM life even with a less severe temperature range.
- o Out-of-phase TMF correlates with isothermal LCF at maximum temperature a 649°C when the total matrix strain range is considered.
- o The total matrix strain experienced in an out-of-phase TMF cycle to 760°C does not correlate with isothermal fatigue life at that temperature.
- o In-phase thermal mechanical fatigue limit is greater than that for isothermal LCF at maximum temperature.
- o In-phase, R = 0.50 TMF tests showed little or no fatigue damage.

APPENDIX A

Task VI. Creep Rupture Data

METCUT RESEARCH ASSOCIATES INC.

MATERIALS ENGINEERING DIVISION

3980 Rosslyn Drive, Cincinnati, Ohio 45209-1196 • Telephone 513-271-5100

Telex II: 810 461-2840 / EasyLink 6291-3788 FAX 513-271-9511

TO: Allison Gas Turbine
General Motors Corp.
Attn: Mary Lee Gambone W05
2001 South Tibbs Avenue
Indianapolis, IN 46241

NUMBER: 1393-46793-1
DATE: December 28, 1988
AUTHORIZATION: H828595
Page 1 of 1

PROJECT: Creep Rupture Testing of (12) 8-Ply SiC/Ti Composite Sheet Specimens Supplied and Identified by Allison Gas Turbine.

Nominal Gage Section: 1.8 x 7.6 x 29.7 mm Long

MRAI No.	Specimen Ident.	Temp. (°C)	Stress (MPa)	Time (hr) to % Creep of 0.1	0.2	0.5	1.0	Rupture Life (hours)	Final Creep (%)	Elong. (%)
C-52780	15L-11	649	558.9	-	-	-	-	(a)	-	4.4
C-53822	26L-3	649	558.9	1.9	18	227	-	467.2	-	1.8
C-53578	26L-2	649	524.0	0.5	1.2	207	720	752.4	1.17	1.9
C-53044	16L-9	649	489.0	4.9	182	-	-	915.2 (b)	.288	-
C-52990	16L-16	760	489.0	.29	11	132	-	187.2	-	2.1
C-53376	16L-3	760	454.1	2.1	17	147	-	147.8	.553	1.6
C-53356	26L-1	760	454.1	.01	.12	1.7	-	2.0	.551	(c)
C-53776	15L-9	760	419.2	(d)	O.L.	10	99	99.5	1.06	1.7
C-53035	15L-3	871	419.2	.08	1.2	-	-	3.0	.345	1.9
C-53747	16L-21	871	384.2	0.3	1.1	-	-	2.5	-	.78
C-53764	26L-4	871	349.3	0.8	3.0	13	24	24.8 (e)	1.17	-
C-53794	15L-6	871	314.4	0.2	0.9	5.1	16	30.5	1.87	3.0

Notes:
(a) Specimen failed approximately 3 minutes after full load was applied.
(b) Specimen unloaded without failure at time shown.
(c) Final elongation not available.
(d) Specimen indicated 0.207% plastic deformation on loading.
(e) Failed near extensometer clamp - final elongation not measured.

Louis J. Fritz, Manager
Creep, Stress Rupture & Tensile Testing
fw

Edward Slattery
Supervisor

METCUT RESEARCH ASSOCIATES INC.

MATERIALS ENGINEERING DIVISION

3980 Rosslyn Drive, Cincinnati, Ohio 45209-1196 • Telephone 513-271-5100
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TO: Allison Gas Turbine
General Motors Corp.
Attn: Mary Lee Gambone W05
2001 South Tibbs Avenue
Indianapolis, IN 46241

NUMBER: 1393-46793-2
DATE: December 28, 1988
AUTHORIZATION: H828595
Page 1 of 1

PROJECT: Creep Rupture Testing of (12) 8-Ply SiC/Ti Composite Sheet Specimens Supplied and Identified by Allison Gas Turbine.

Nominal Gage Section: 1.8 x 7.6 x 30.5 mm Long

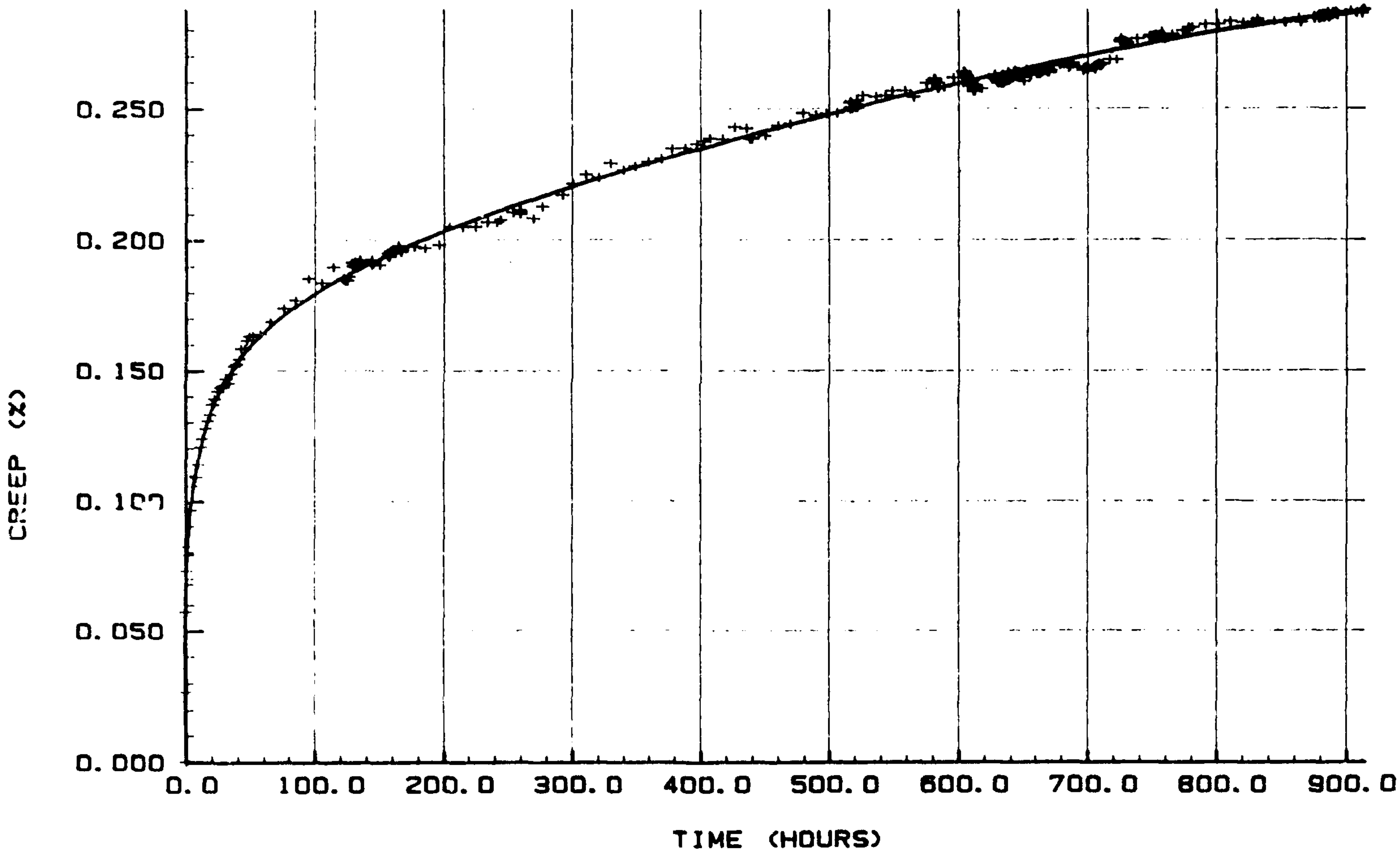
MRAI No.	Specimen Ident.	Temp. (°C)	Stress (MPa)	Time (hr)to % Creep of 0.1	0.2	0.5	1.0	Rupture Life (hours)	Final Creep (%)	Elong. (%)
C-53040	25T-4	649	90.8	(a)	.01	.27	1.3	1.7	1.07	0.8
C-53377	25T-2	649	69.9	.02	.11	.94	3.9	34.4	5.2	9.3
C-53752	25T-5	649	55.9	.19	.59	2.9	8.4	64.2	6.0	7.3
C-53829	24T-4	649	34.9	2.5	6.1	17	34	408.7	-	12.2
C-53793	24T-9	760	48.9	.28	.42	0.8	1.4	12.7	17.8	18.6
C-52773	15T-2	760	34.9	.14	.38	1.3	3.1	79.3	-	12.1
C-53579	24T-8	760	21.0	.62	1.2	3.1	6.1	1000.6 (b)	61.3	76.6
C-53823	25T-7	871	27.9	.02	.05	.12	.24	16.1	-	124.7
C-53836	15T-9	871	21.0	-	-	-	-	(c)	-	-
C-53837	15T-10	871	21.0	.10	.25	.63	1.3	1008.0 (d)	-	-
C-53012	24T-7	871	14.0	.13	.26	.66	1.3	1079.7 (d)	-	-
C-53372	15T-8	871	7.0	-	-	-	-	(e)	-	-

Notes:
(a) Specimen indicated 0.134% plastic deformation on loading.
(b) Specimen unloaded without failure at time shown.
(c) Void test; specimen broke while being loaded.
(d) Specimen unloaded without failure; specimen broke while removing from test frame.
(e) Void test; specimen broke while attaching extensometer.

Louis J. Fritz, Manager
Creep, Stress Rupture & Tensile Testing
fw

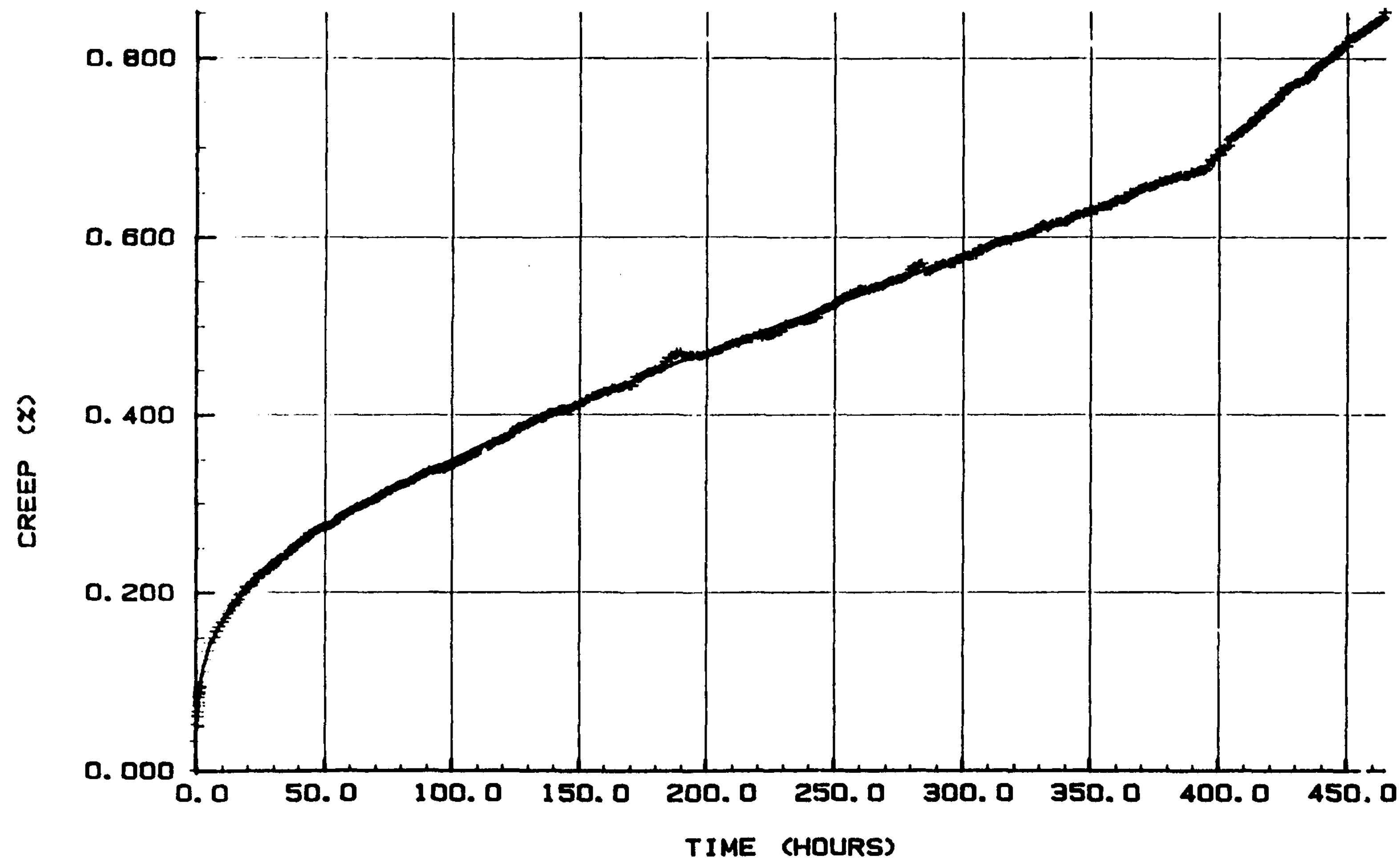
Edward Slattery
Supervisor

1393-46793   C53044   SPECIMEN NO   16L-9   649°C   489.0 MPa
.1%-4.9 HRS   .2%-182 HRS



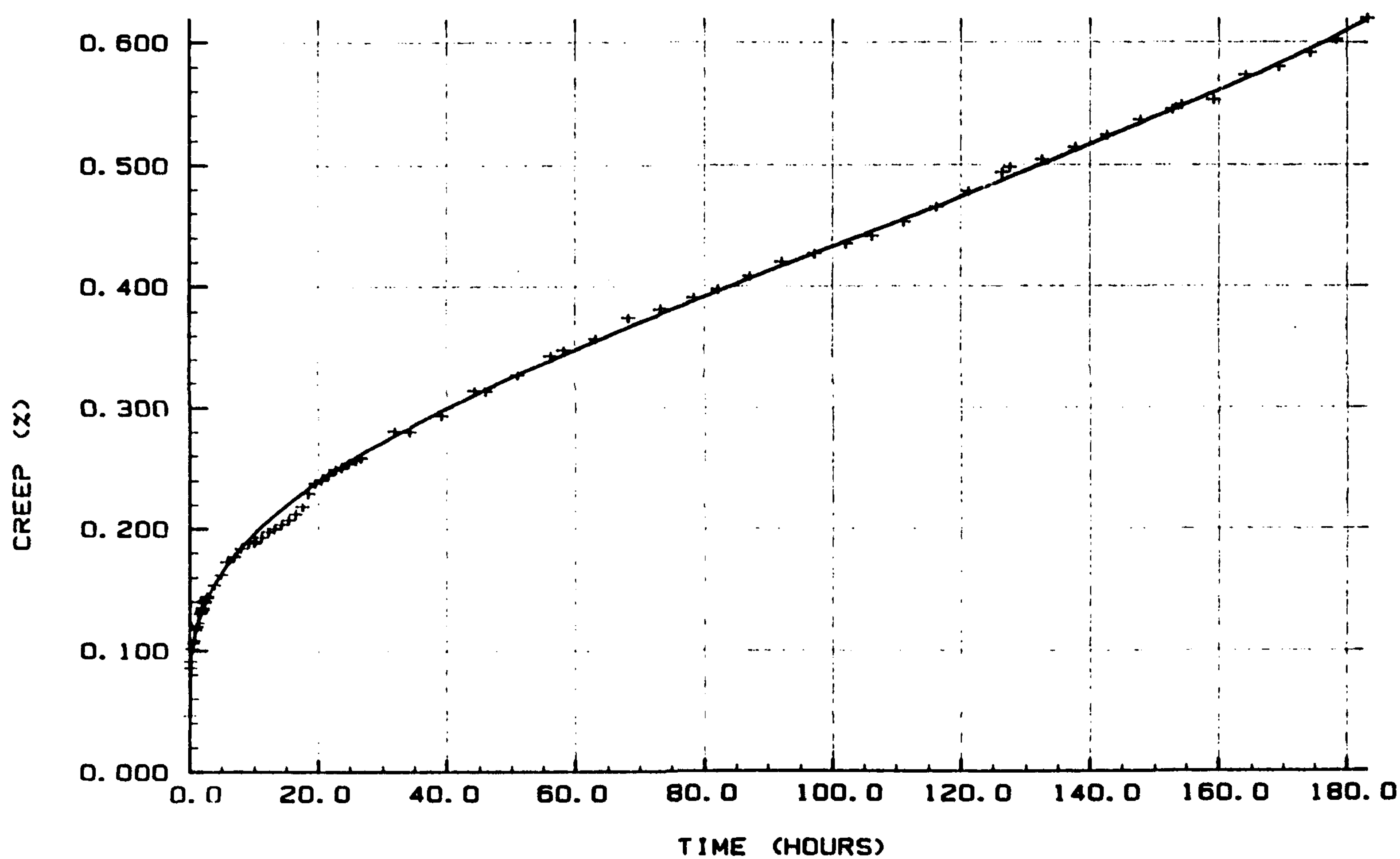
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45208 / (513) 271-5100

1393-46793 C43822 SPECIMEN NO 26L3 649°C 558.9 MPa
.1%-1.9 HRS .2%-17.9 HRS .5%-227 HRS



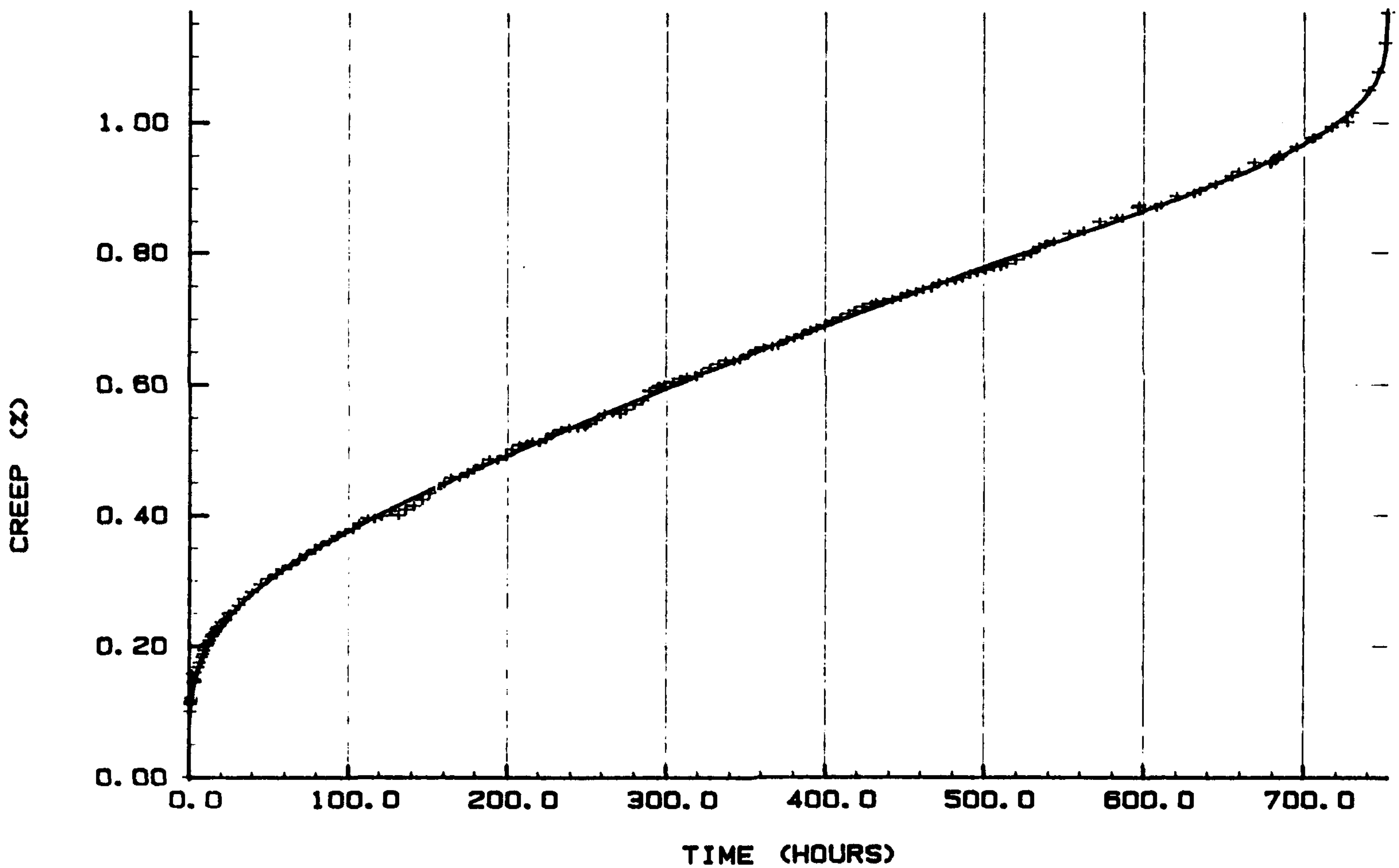
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C52990 SPECIMEN NO 16L-16 760°C 489.0 MPa
.1%-.29 HRS .2%-10.8 HRS .5%-132 HRS
.0461% PLASTIC CREEP ON LOADING



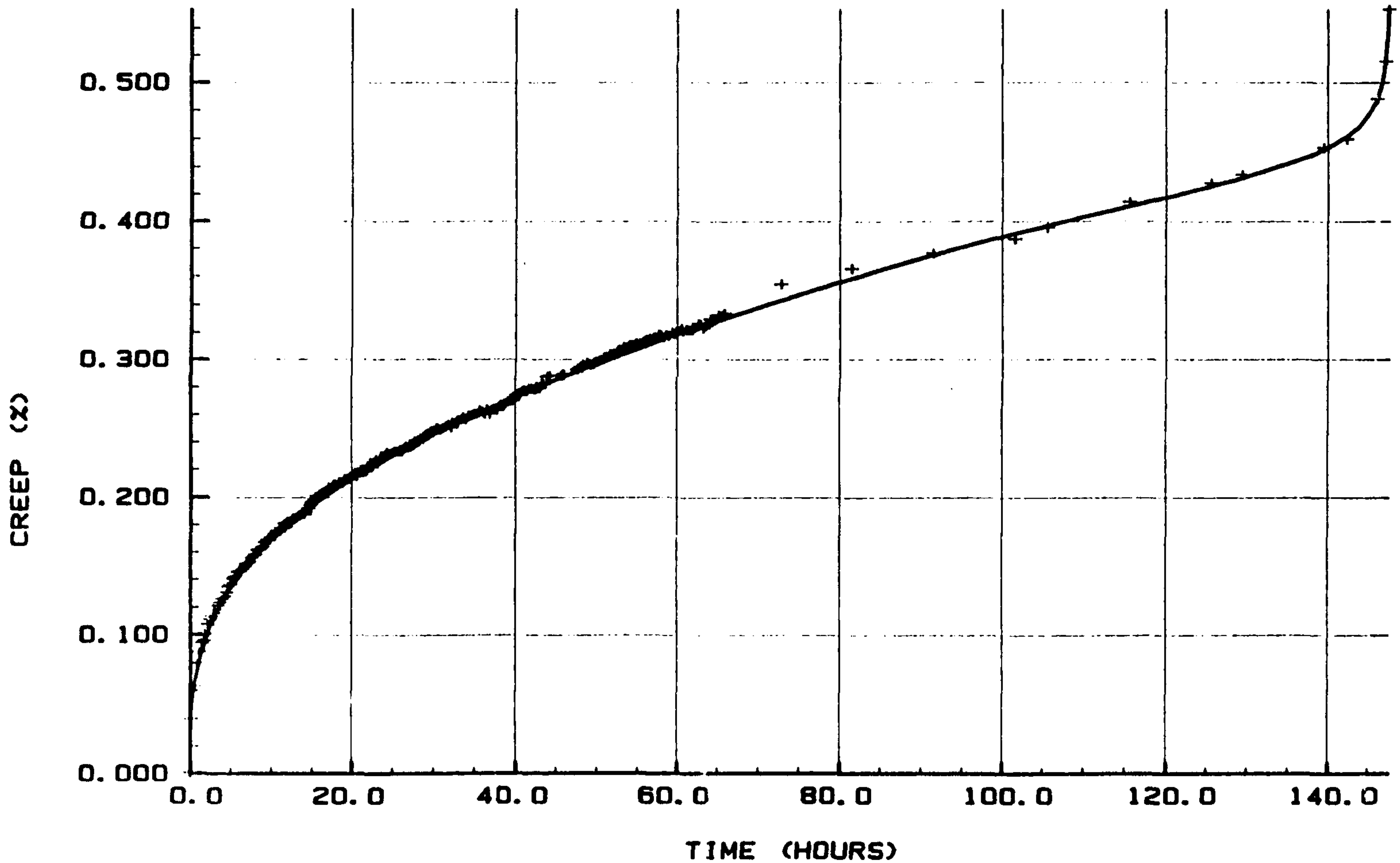
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793   C53578   SPECIMEN NO   26L-2   649°C   524.0 MPa
.1%-.5 HRS   .2%-1.2 HRS   .5%-207 HRS   1.0%-720 HRS



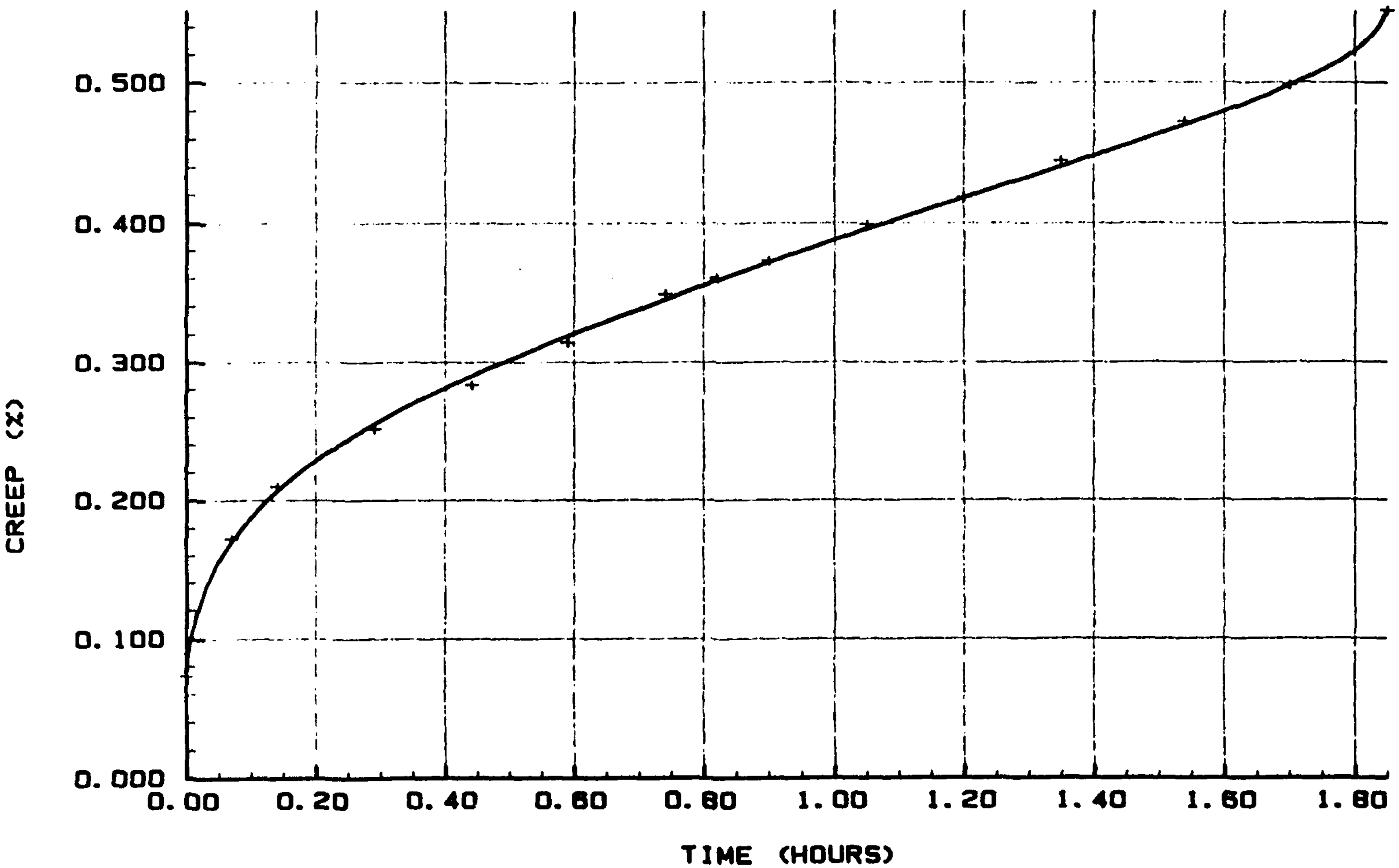
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive,   Cincinnati, Ohio   45209 / (513) 271-5100

1393-46793 C53376 SPECIMEN NO 16L-3 760°C 454.1 MPa
.1%-2.1 HRS .2%-16.6 HRS .5%-147 HRS



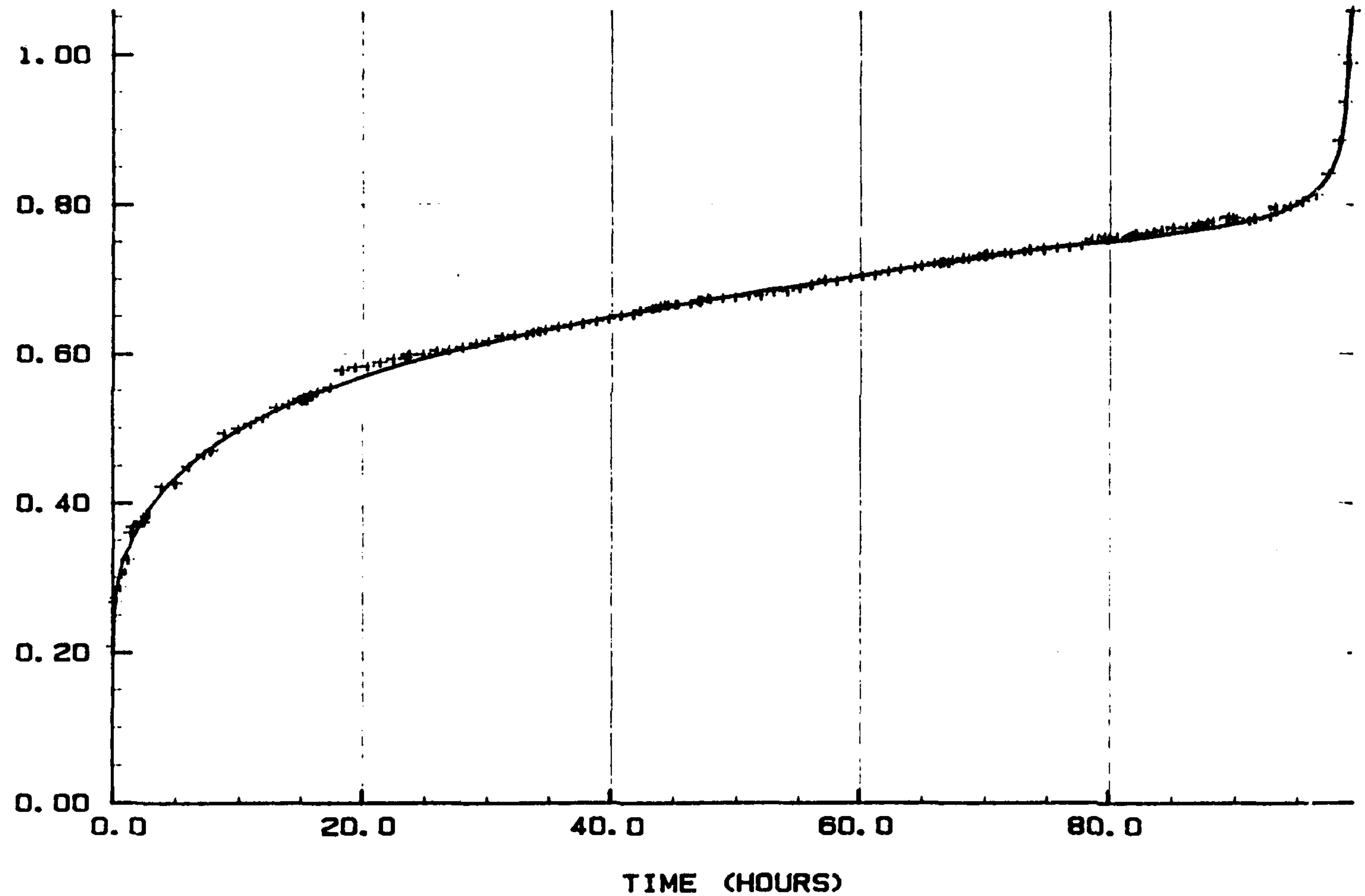
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C53356 SPECIMEN NO 26L-1 760°C 454.1 MPa
.1%-0.007 HRS .2%-0.12 HRS .5%-1.7 HRS
0.072% PLASTIC CREEP ON LOADING



METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C53776 SPECIMEN NO 15L-9 760°C 419.2 MPa
.1%-OL .2%-OL .5%-10.3 HRS 1.0%-99 HRS
0.207% PLASTIC CREEP ON LOADING



METCUT RESEARCH ASSOCIATES INC.
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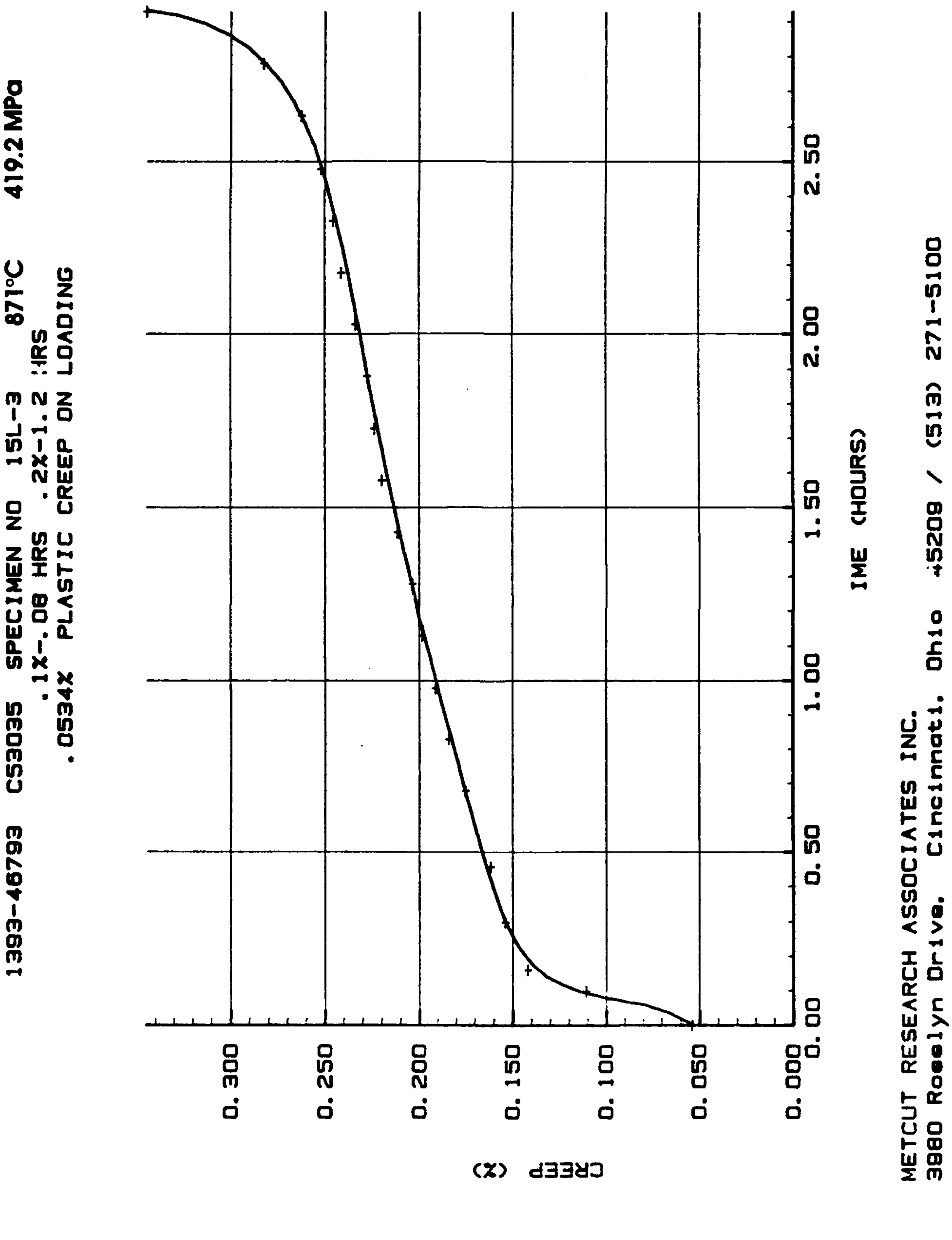
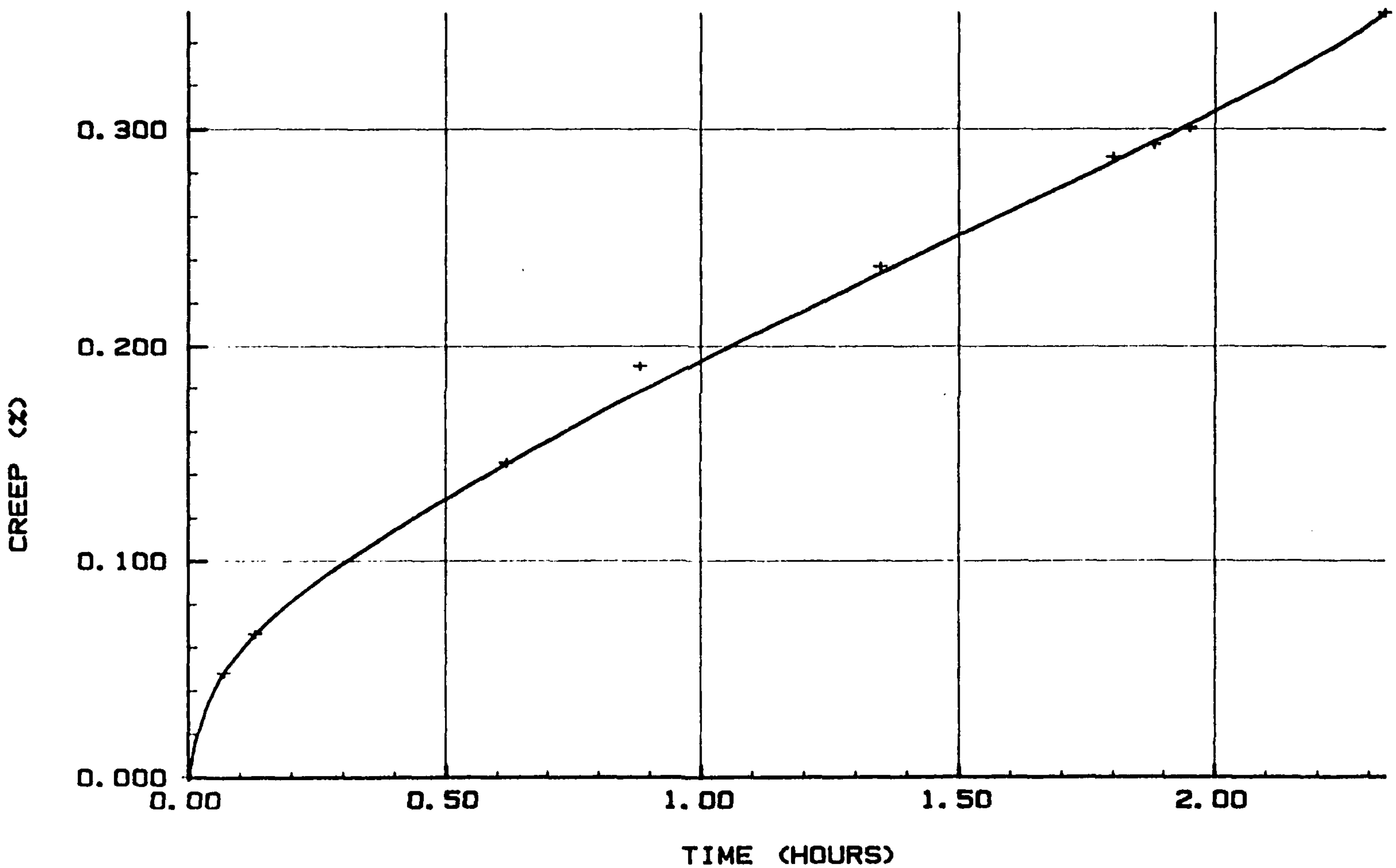
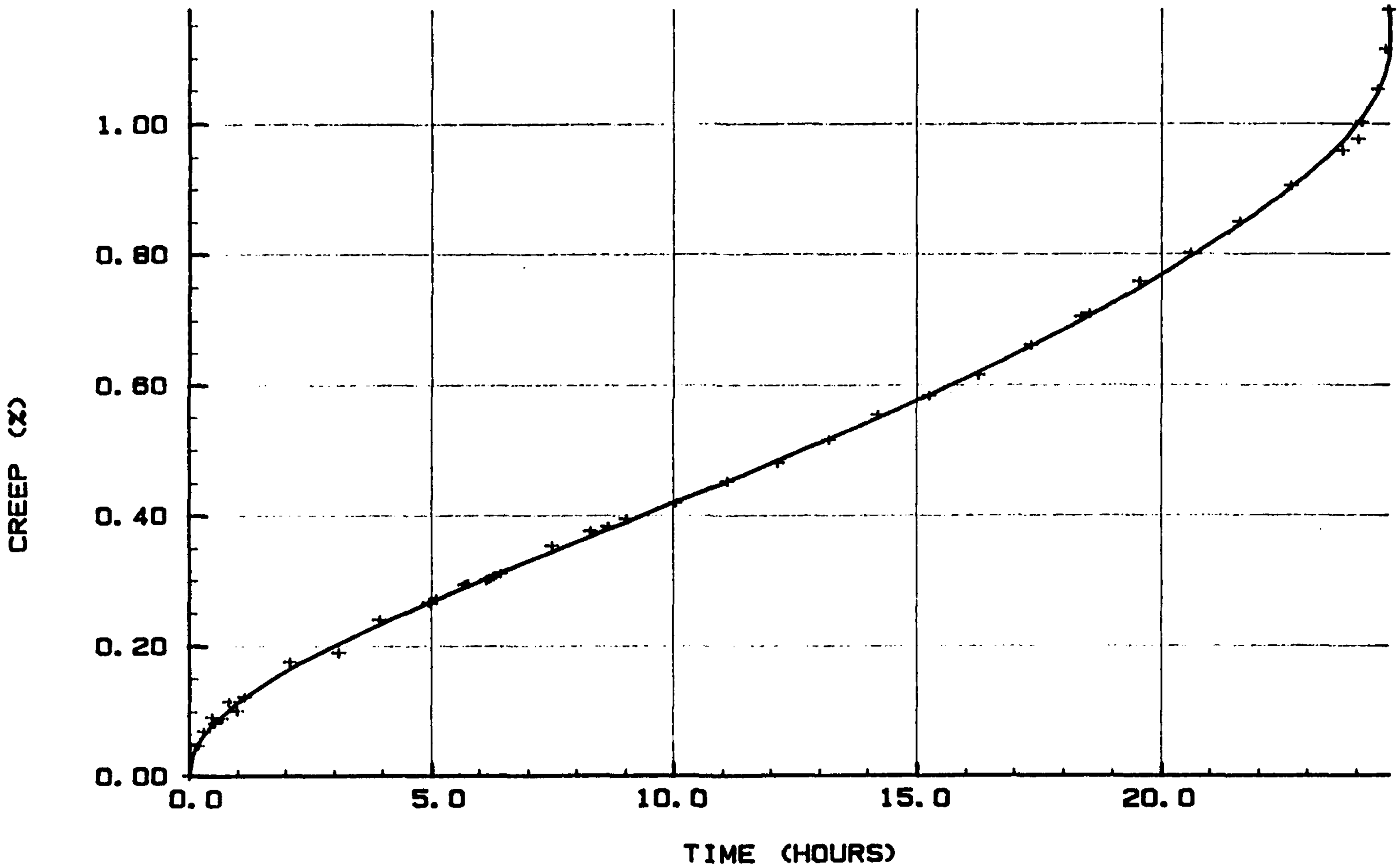

1393-46793 C53035 SPECIMEN NO 15L-3 871°C 419.2 MPa
.1%-.08 HRS .2%-1.2 HRS
.0534% PLASTIC CREEP ON LOADING
CREEP (%)
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.00
0.50
1.00
1.50
2.00
2.50
TIME (HOURS)
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45208 / (513) 271-5100

1393-46793 C53747 SPECIMEN NO 16L-21 871°C 384.2 MPa
.1%-0.31 HRS .2%-1.1 HRS



METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive. Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C53764 SPECIMEN NO 26L-4 871°C 349.3 MPa
.1%-0.78 HRS .2%-3.0 HRS .5%-12.7 HRS 1.0%-24 HRS



METCUT RESEARCH ASSOCIATES INC.
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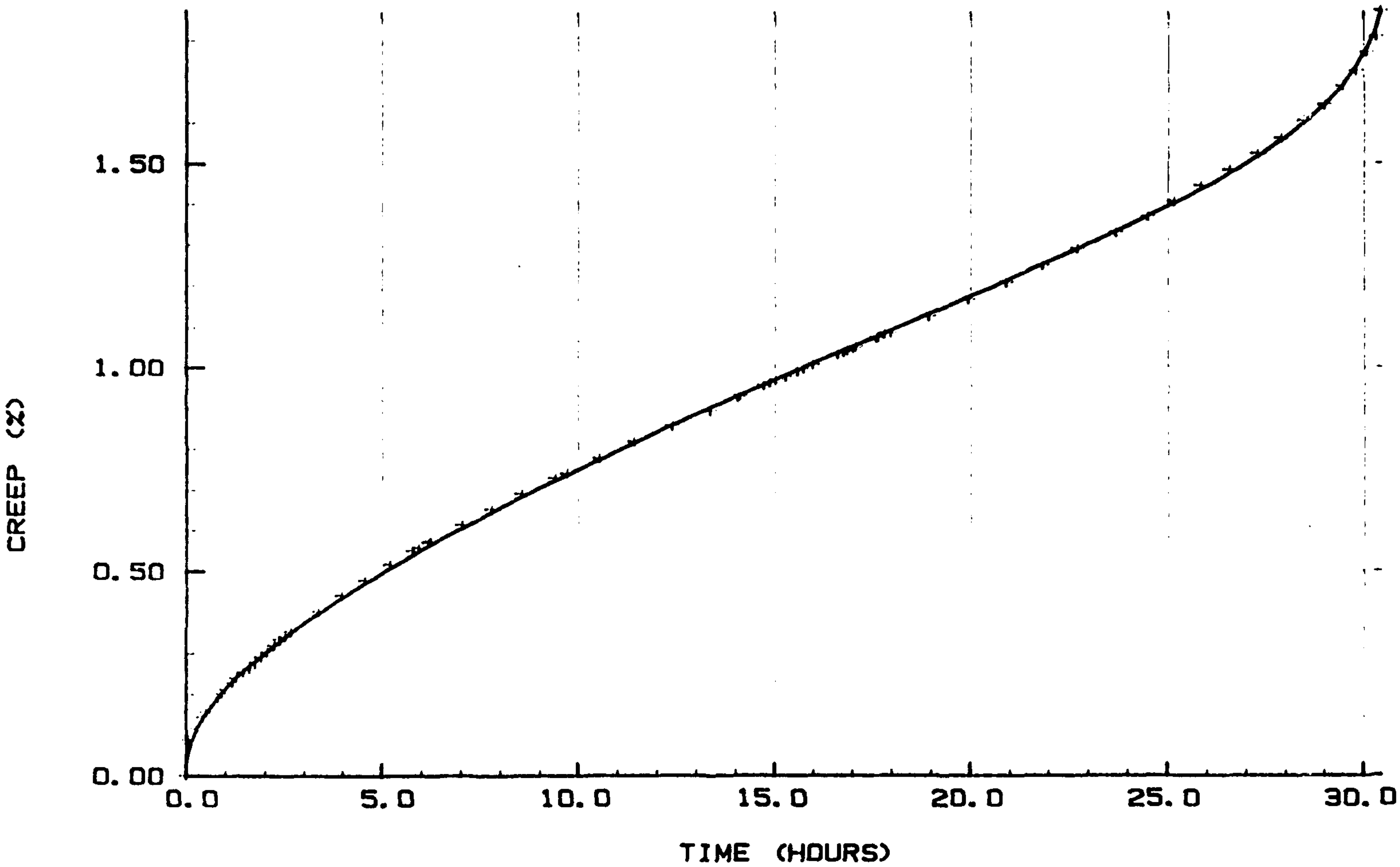
1393-48793 C53794 SPECIMEN NO 15L-8 871°C 314.4 MPa
.1%-0.21 HRS .2%-0.90 HRS .5%-5.1 HRS 1.0%-15.7 HRS



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METCUT RESEARCH ASSOCIATES INC.

MATERIALS ENGINEERING DIVISION

3980 Rosslyn Drive, Cincinnati, Ohio 45209-1196 • Telephone 513-271-5100

Telex II: 810 461-2840 EasyLink 6291-3788 FAX 513-271-9511

TO: Allison Gas Turbine
General Motors Corp.
Attn: Mary Lee Gambone W05
2001 South Tibbs Avenue
Indianapolis, IN 46241

NUMBER: 1393-46793-2
DATE: December 28, 1988
AUTHORIZATION: H828595
Page 1 of 1

PROJECT: Creep Rupture Testing of (12) 8-Ply SiC/Ti Composite Sheet Specimens Supplied and Identified by Allison Gas Turbine.

Nominal Gage Section: 1.8 x 7.6 x 30.5 mm Long

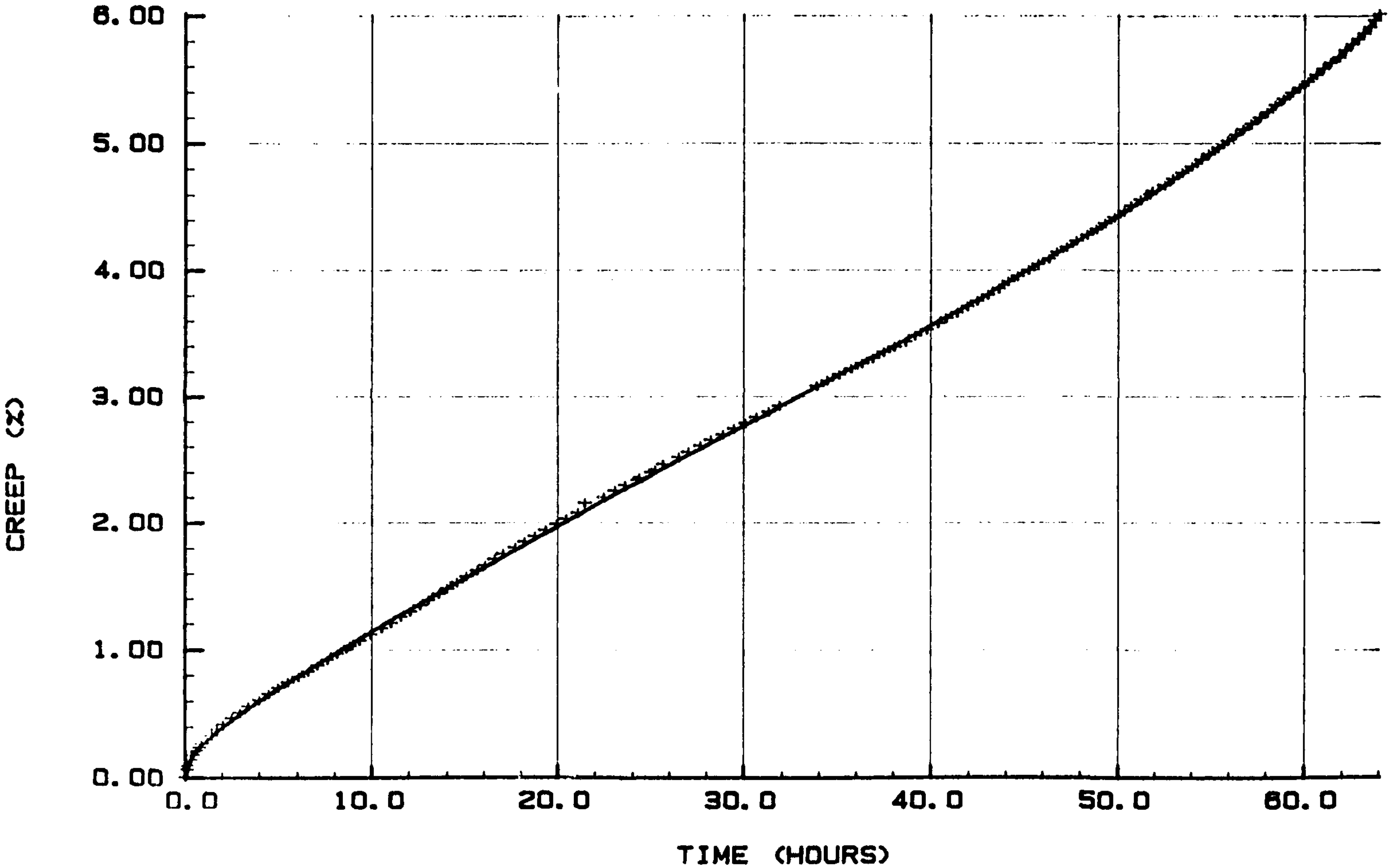
MRAI No.	Specimen Ident.	Temp. (°C)	Stress (MPa)	Time (hr) to % Creep of 0.1	0.2	0.5	1.0	Rupture Life (hours)	Final Creep (%)	Elong. (%)
C-53040	25T-4	649	90.8	(a)	.01	.27	1.3	1.7	1.07	0.8
C-53377	25T-2	649	69.9	.02	.11	.94	3.9	34.4	5.2	9.3
C-53752	25T-5	649	55.9	.19	.59	2.9	8.4	64.2	6.0	7.3
C-53829	24T-4	649	34.9	2.5	6.1	17	34	408.7	-	12.2
C-53793	24T-9	760	48.9	.28	.42	0.8	1.4	12.7	17.8	18.6
C-52773	15T-2	760	34.9	.14	.38	1.3	3.1	79.3	·	12.1
C-53579	24T-8	760	21.0	.62	1.2	3.1	6.1	1000.6 (b)	61.3	76.6
C-53823	25T-7	871	27.9	.02	.05	.12	.24	16.1	-	124.7
C-53836	15T-9	871	21.0	-	-	-	-	(c)	-	-
C-53837	15T-10	871	21.0	.10	.25	.63	1.3	1008.0 (d)	-	-
C-53012	24T-7	871	14.0	.13	.26	.66	1.3	1079.7 (d)	-	-
C-53372	15T-8	871	7.0	-	-	-	-	(e)	-	-

Notes:
(a) Specimen indicated 0.134% plastic deformation on loading.
(b) Specimen unloaded without failure at time shown.
(c) Void test; specimen broke while being loaded.
(d) Specimen unloaded without failure; specimen broke while removing from test frame.
(e) Void test; specimen broke while attaching extensometer.

Louis J. Fritz, Manager
Creep, Stress Rupture & Tensile Testing
fw

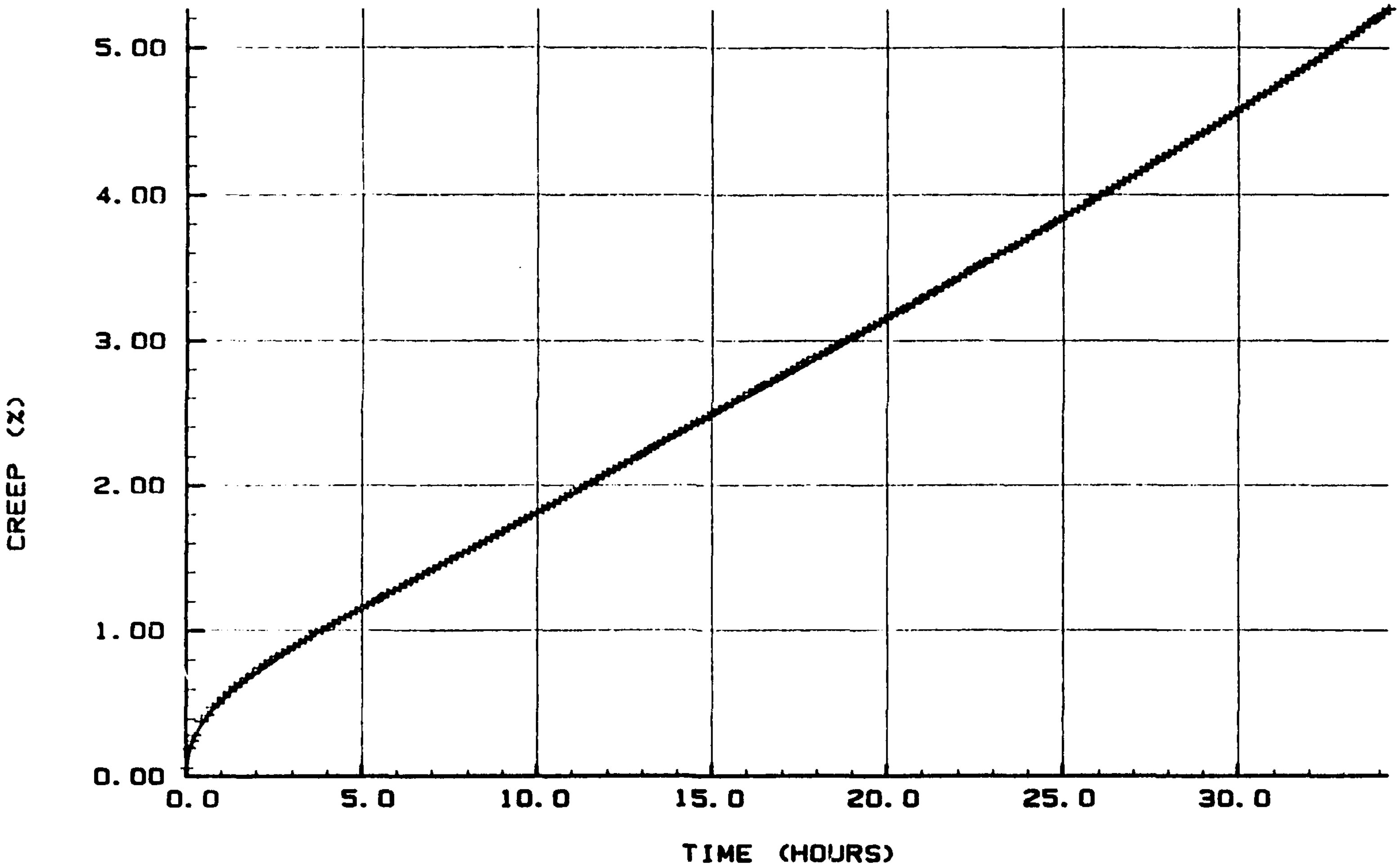
Edward Slattery
Supervisor

1393-48793 C53752 SPECIMEN NO 25T-5 649°C 55.9 MPa
.1%-0.19 HRS .2%-0.59 HRS .5%-2.9 HRS 1.0%-8.4 HRS 2.0%-20 HRS



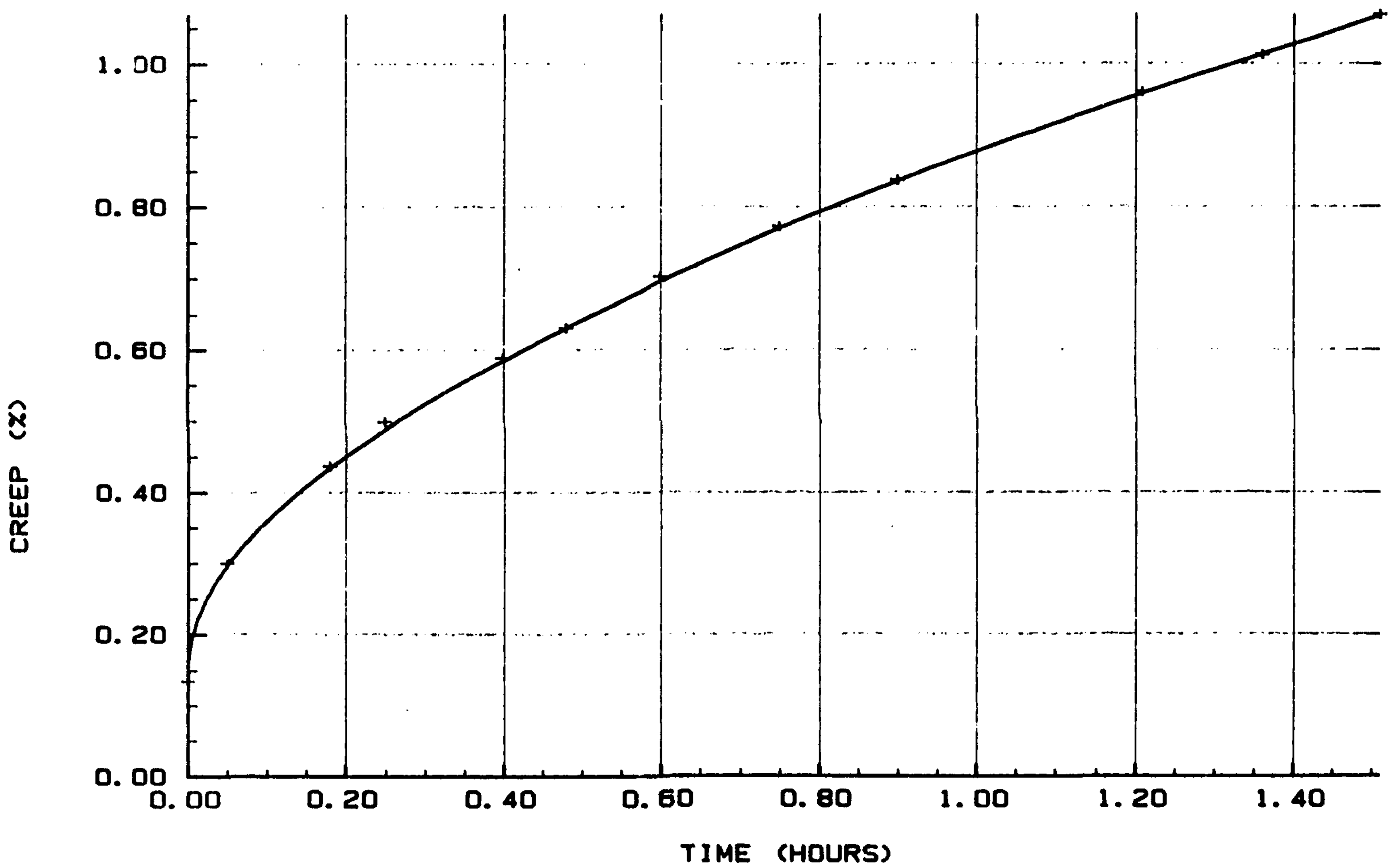
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C53377 SPECIMEN NO 25T-2 649°C 69.9 MPa
.1%-.02 HRS . %-.11 HRS .5%-.94 HRS 1%-3.9 HRS 2%-11.5 HRS
0.052% PLASTIC CREEP ON LOADING



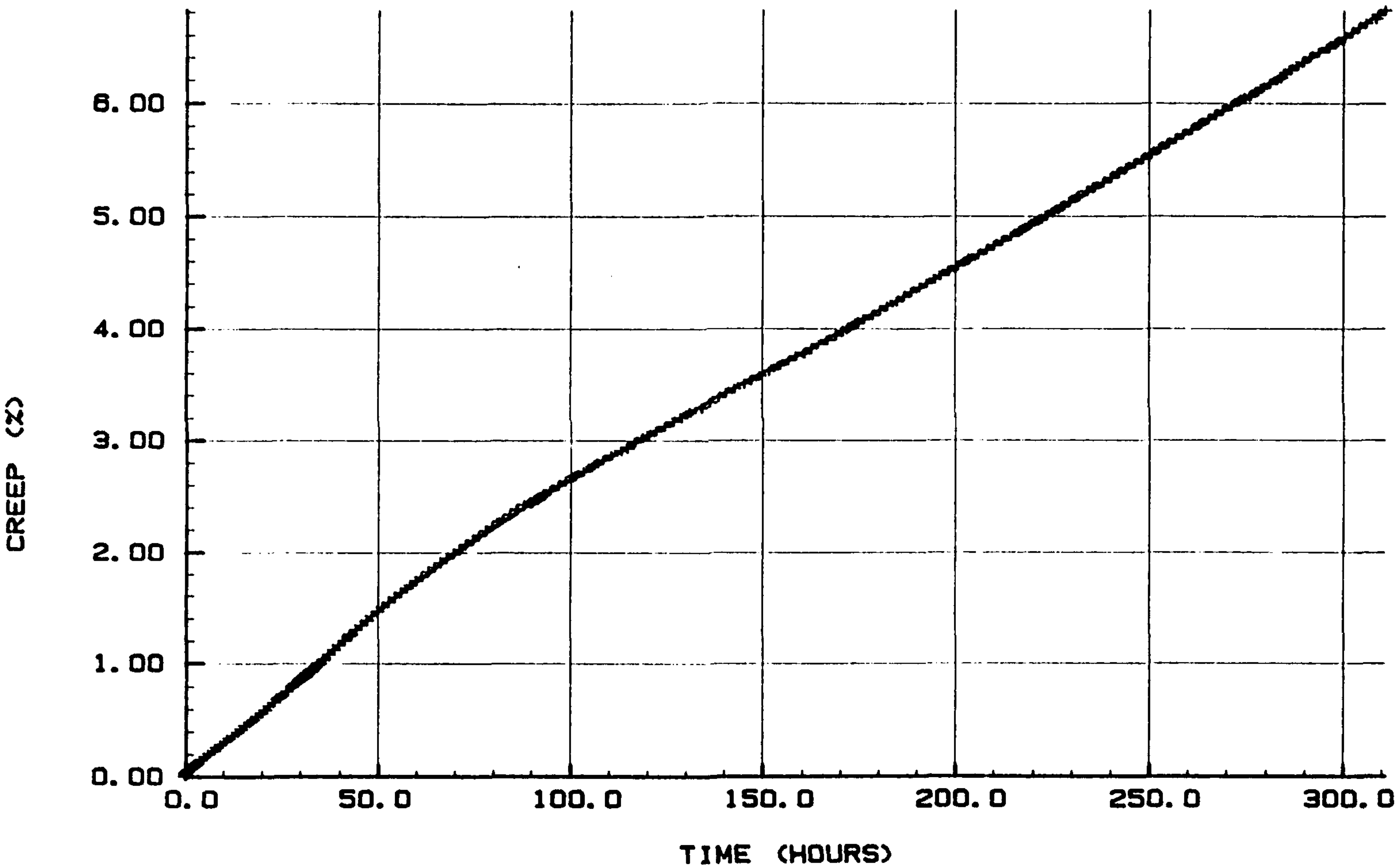
ETCUT RESEARCH ASSOCIATES INC.
980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C53040 SPECIMEN NO 25T4 649°C 90.8 MPa
.1%-OL .2%-.01 HRS .5%-.27 HRS 1.0%-1.3 HRS
.1338% PLASTIC CREEP ON LOADING



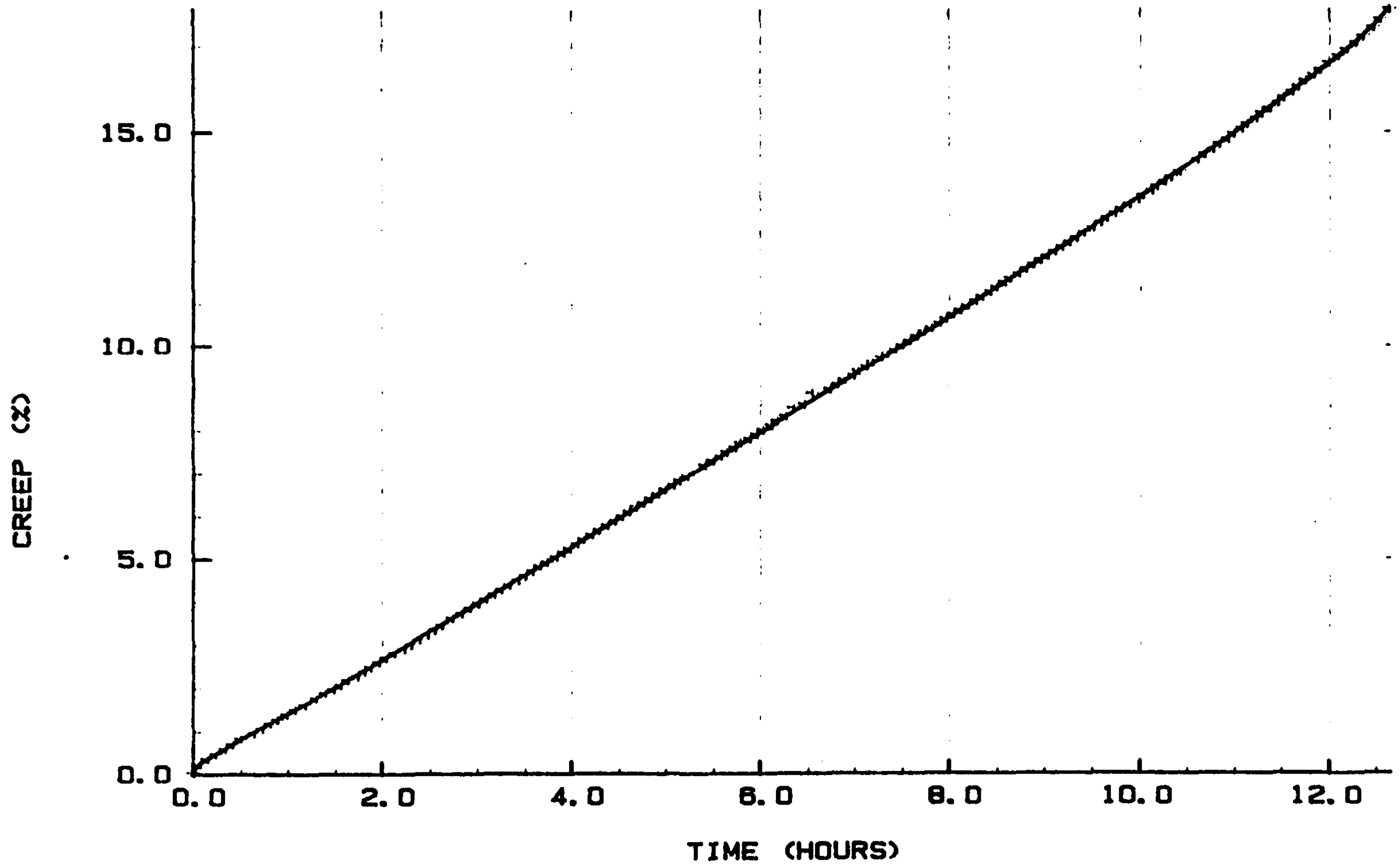
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C53828 SPECIMEN NO 24T-4 649°C 34.9 MPa
.1%-2.5 HRS .2%-6.1 HRS .5%-17.2 HRS 1.0%-34 HRS 2.0%-71 HRS



METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45208 / (513) 271-5100

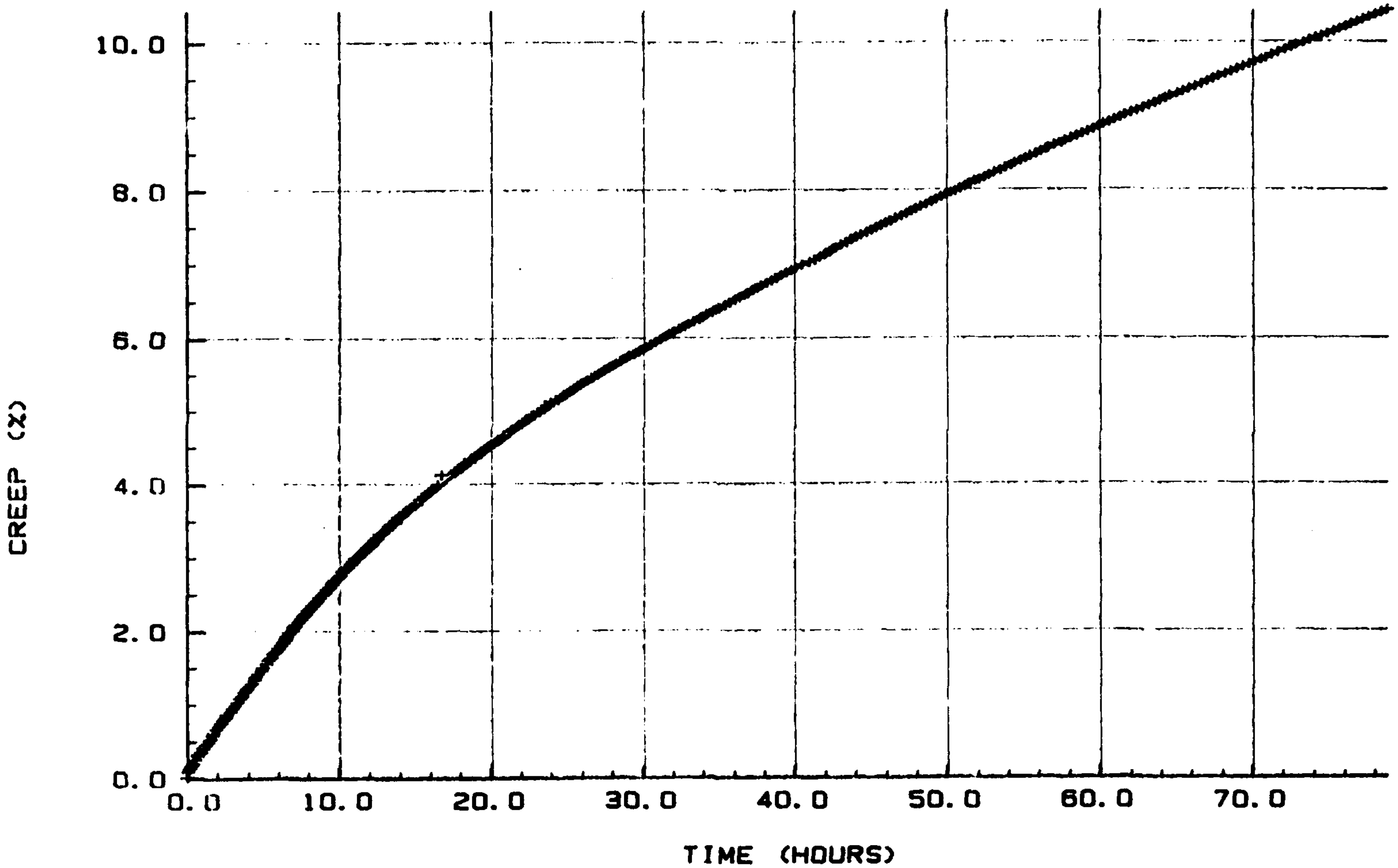
1393-48793 C53793 SPECIMEN NO 24T-9 760°C 48.9 MPa
.1%-.28 HRS .2%-.42 HRS .5%-.80 HRS 1.0%-1.4 HRS 2.0%-2.7 HRS
0.031% PLASTIC CREEP ON LOADING



METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C52773 SPECIMEN NO 15T-2 760°C 34.9 MPa

.1%-.14 HRS .2%-.38 HRS .5%-1.3 HRS 1.0%-3.1 HRS 2.0%-6.9 HRS



METCUT RESEARCH ASSOCIATES INC.
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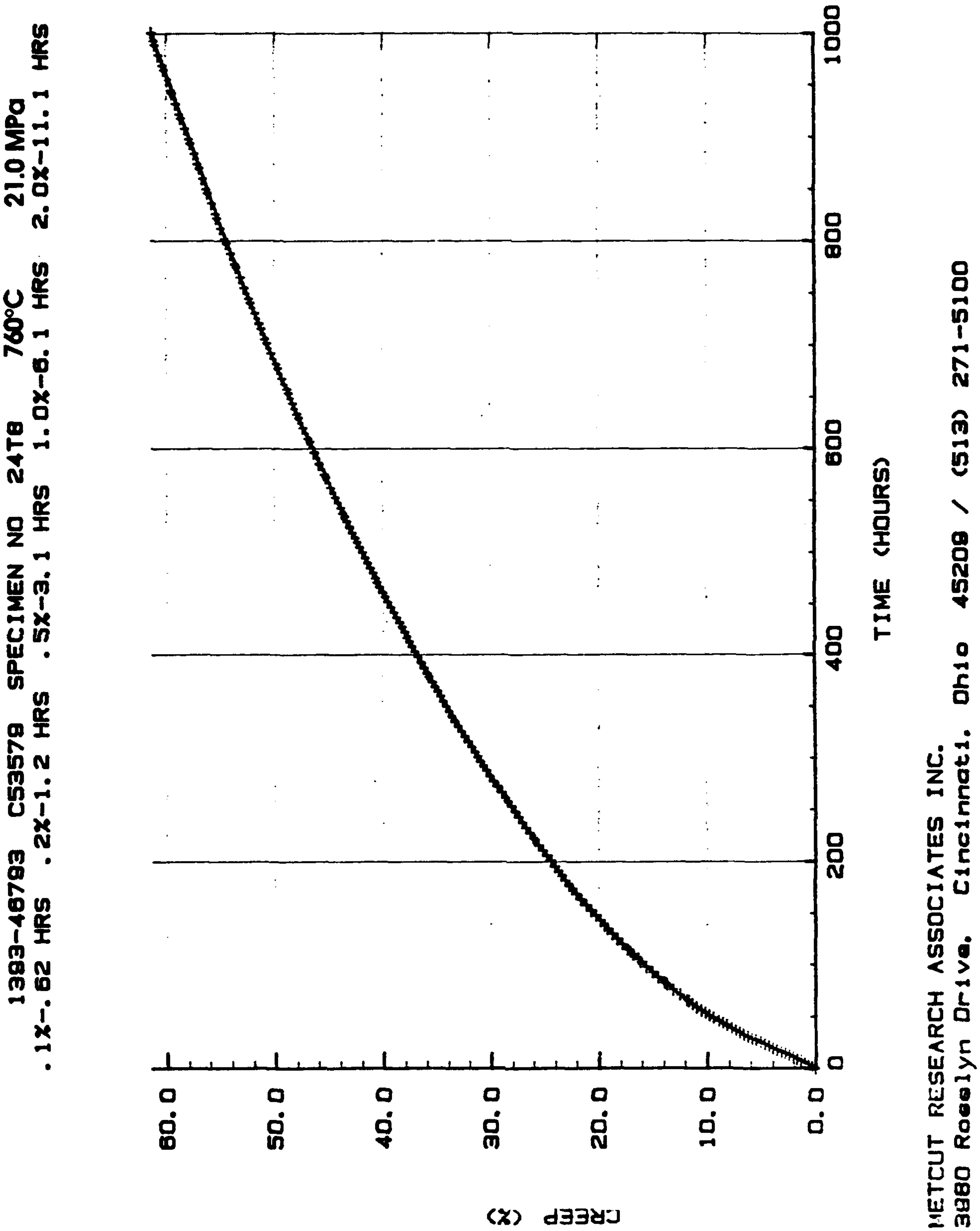
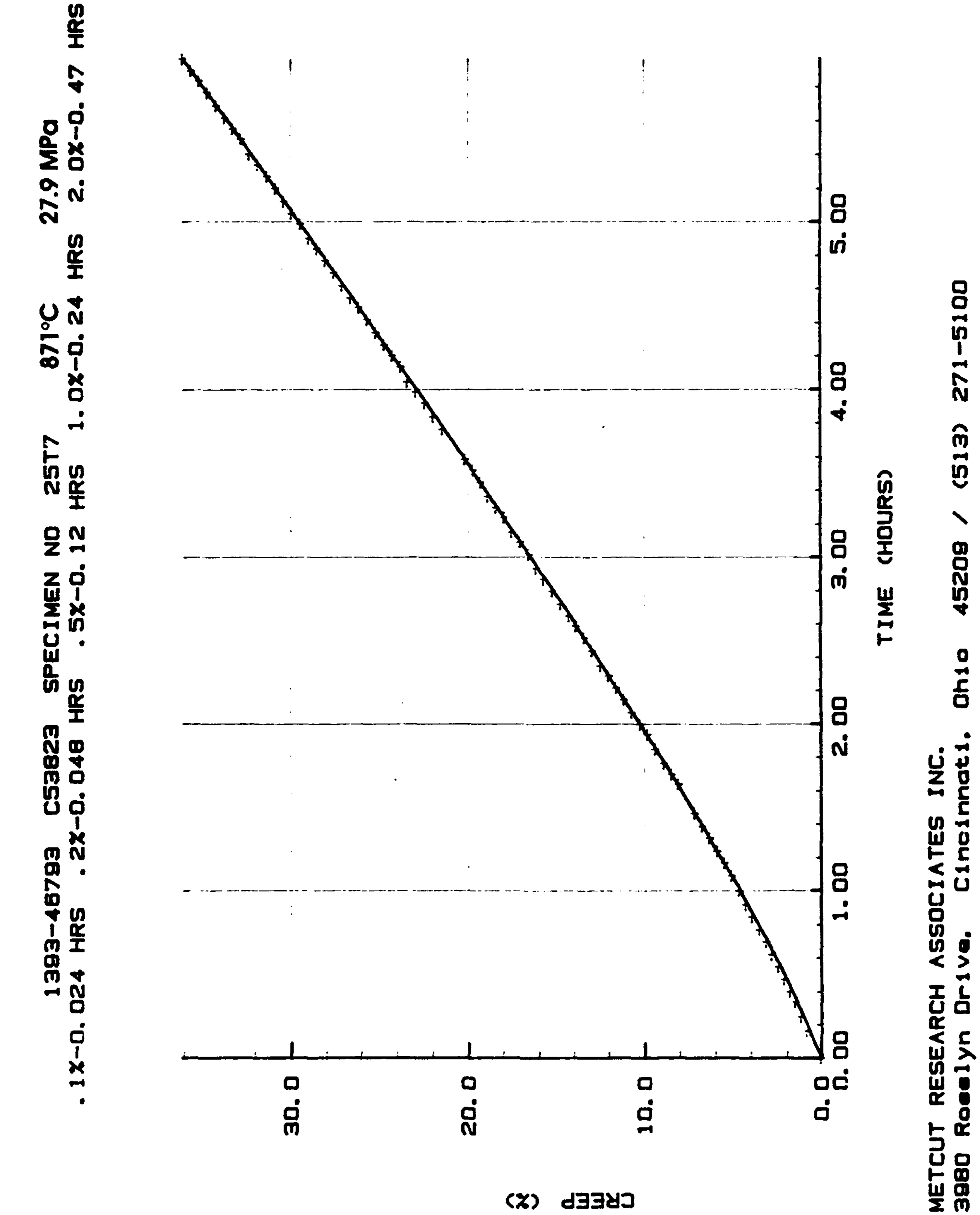
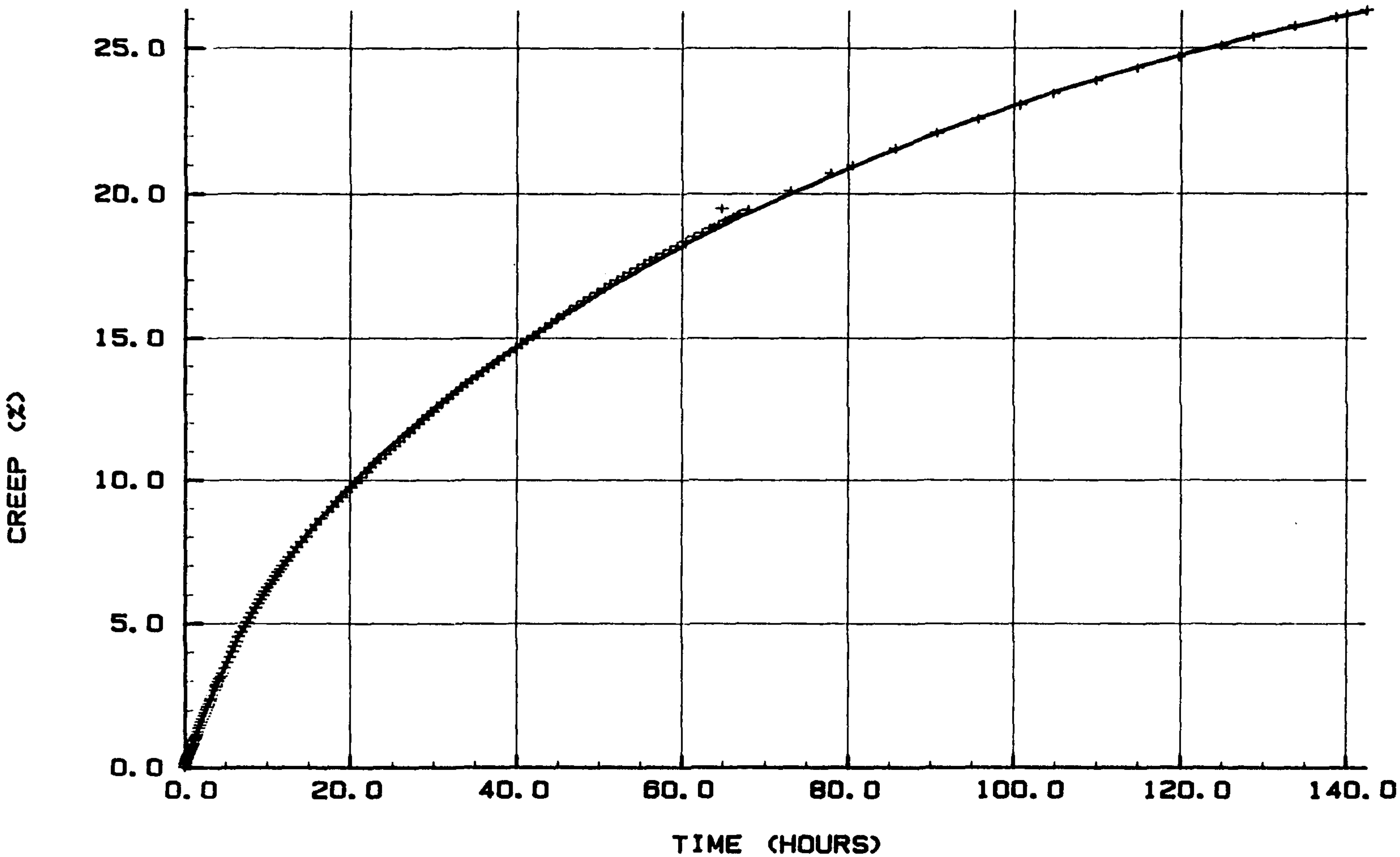

1393-48793 C53579 SPECIMEN NO 24T8 760°C 21.0 MPa
.1%-.62 HRS .2%-1.2 HRS .5%-3.1 HRS 1.0%-6.1 HRS 2.0%-11.1 HRS
CREEP (%)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
0
200
400
600
800
1000
TIME (HOURS)
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive. Cincinnati. Ohio 45209 / (513) 271-5100



1393-46793 C53823 SPECIMEN NO 25T7 871°C 27.9 MPa
.1%-0.024 HRS .2%-0.048 HRS .5%-0.12 HRS 1.0%-0.24 HRS 2.0%-0.47 HRS
CREEP (%)
0.0
10.0
20.0
30.0
0.00
1.00
2.00
3.00
4.00
5.00
TIME (HOURS)
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive. Cincinnati. Ohio 45209 / (513) 271-5100

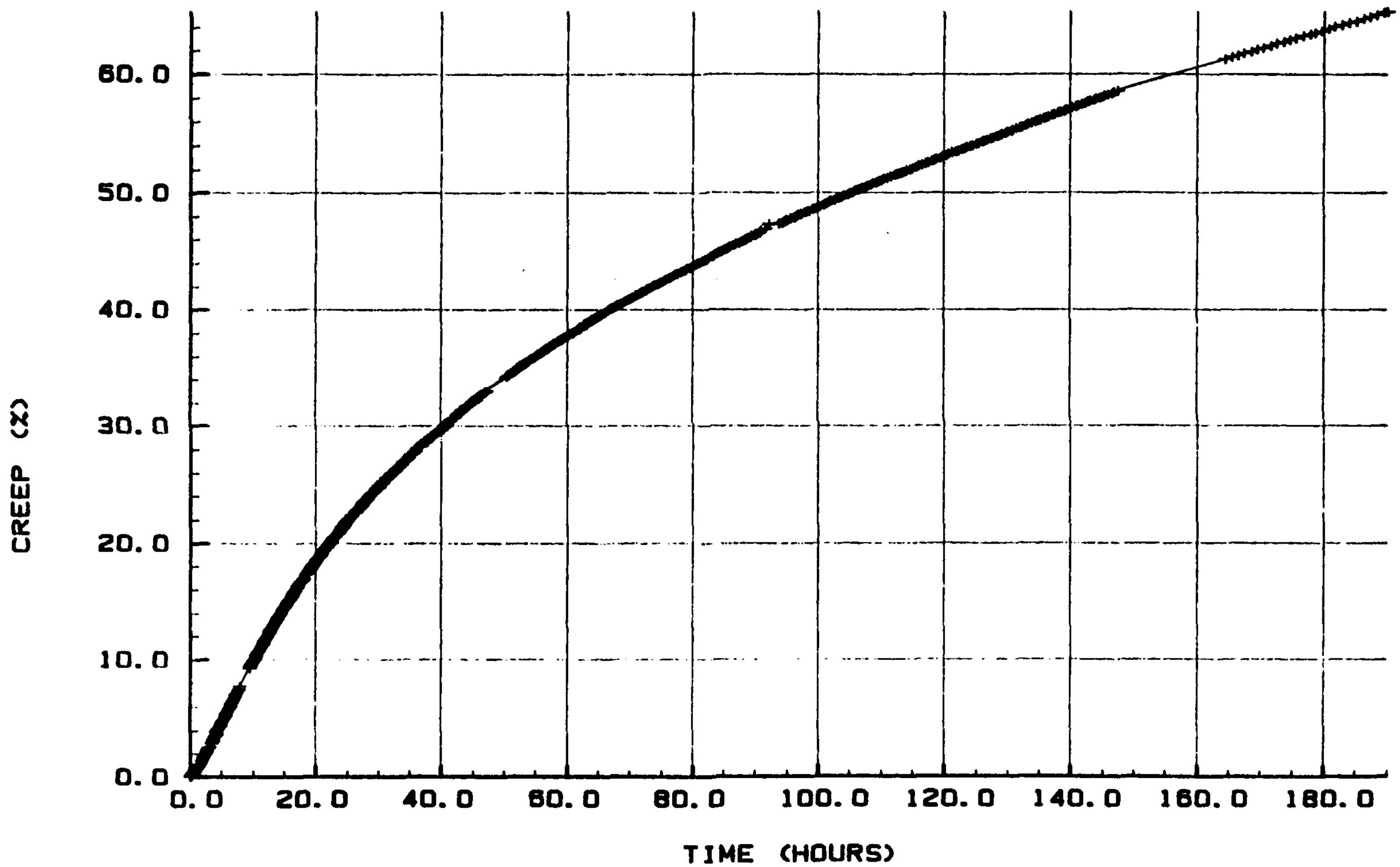
1393-48793   C53837   SPECIMEN NO   15T-10   871°C   21.0 MPa
.1%-0.10 HRS   .2%-0.25 HRS   .5%-0.63 HRS   1.0%-1.3 HRS   2.0%-2.5 HRS



METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C53012 SPECIMEN NO 24T-7 871°C 14.0 MPa

.1%-0.13 HRS .2%-0.26 HRS .5%-0.66 HRS 1.0%-1.3 HRS 2.0%-2.4 HRS



METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

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MATERIALS ENGINEERING DIVISION

3980 Rosslyn Drive, Cincinnati, Ohio 45209-1196 • Telephone 513-271-5100

Telex II: 810 461-2840 · EasyLink 6291-3788 · FAX 513-271-9511

TO: Allison Gas Turbine
General Motors Corp.
Attn: Mary Lee Gambone W05
2001 South Tibbs Avenue
Indianapolis, IN 46241

NUMBER: 1393-46793-3
DATE: December 28, 1988
AUTHORIZATION: H828595
Page 1 of 1

PROJECT: Creep Rupture Testing of (12) 8-Ply SiC/Ti Composite Sheet Specimens Supplied and Identified by Allison Gas Turbine.

Nominal Gage Section: "t" x 7.6 x 30.5 mm Long

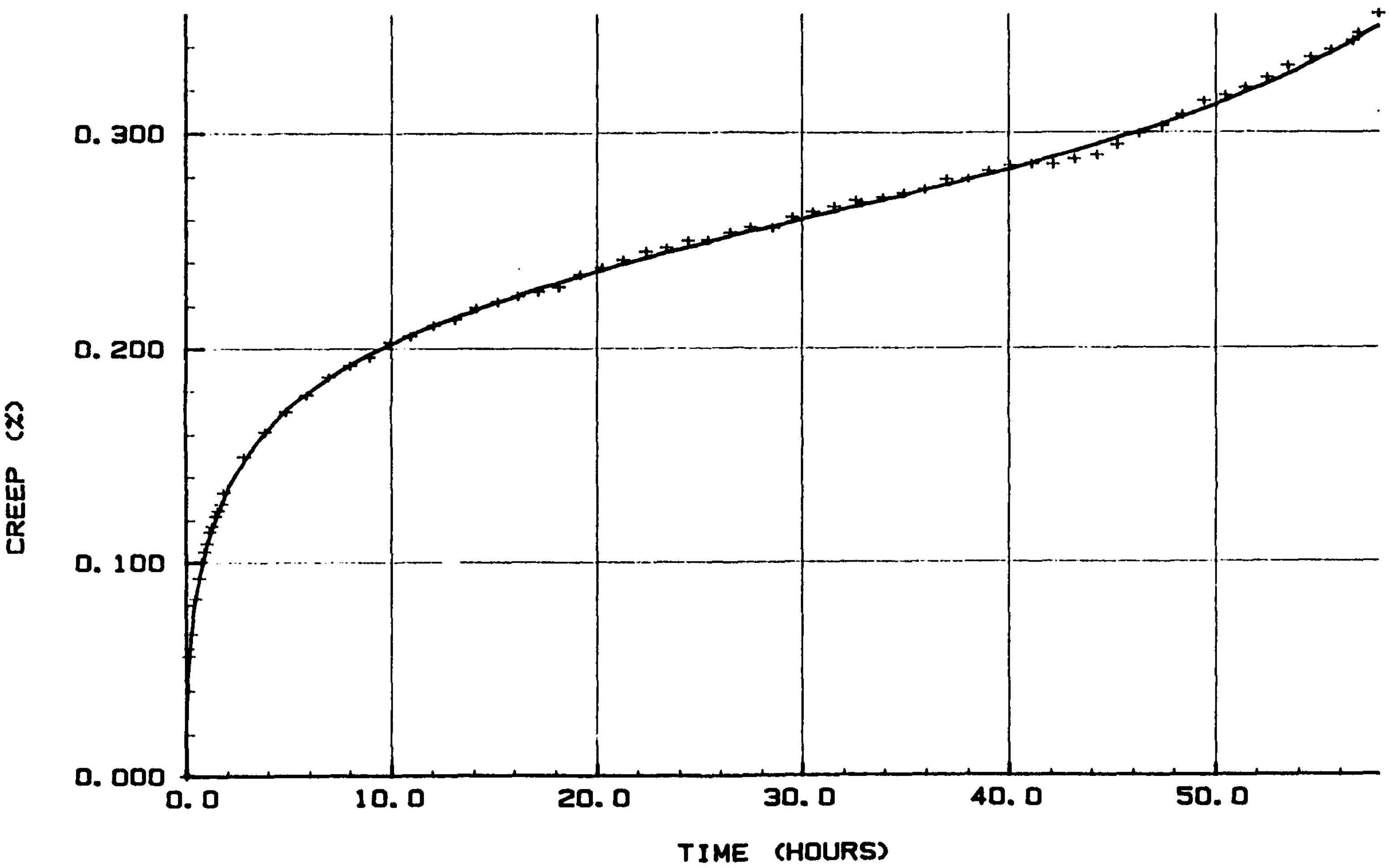
MRAI No.	Specimen Ident.	Temp. (°C)	Stress (MPa)	Time (hr) to % Creep of 0.1	0.2	0.5	1.0	Rupture Life (hours)	Final Creep (%)	Elong. (%)
C-53960	28L-1	649	628.8	0.84	9.6	-	-	58.4	.355	1.3
C-54001	30L-7	649	628.8	1.3	28	-	-	416.2 (a)	.515	0.9
C-53994	28L-8	760	510.0	1.3	6.3	-	-	11.4	.326	3.4
C-54016	30L-10	760	510.0	0.52	4.8	49	121	121.5	1.03	2.7
C-54069	32-3	760	300.4	0.17	1.7	16	-	16.1	.502	2.6
C-54085	33-1	760	300.4	0.25	2.3	-	-	20.6	.429	1.5
C-54130	32-10	760	188.6	3.0	66	-	-	1005.4 (b)	.323	-
C-54255	33-2	760	188.6	0.53	5.4	-	-	1001.9 (b)	.499	-
C-54093	35-1	760	188.6	0.07	0.3	6.1	7.1	7.3	1.20	2.7
C-54104	45-3	760	188.6	0.07	0.7	32	76	76.2	1.34	3.4
C-54284	35-5	760	125.8	0.67	1.5	334	-	1011.2 (b)	.579	-
C-54283	45-5	760	125.8	0.37	2.8	-	-	1011.3 (b)	.463	-

Notes:
(a) Specimen went 21°C over test temperature approximately 190 hours after start of test (returned to temperature in 3 hours).
(b) Specimen unloaded without failure at time shown.

Louis J. Fritz, Manager
Creep, Stress Rupture & Tensile Testing
fw

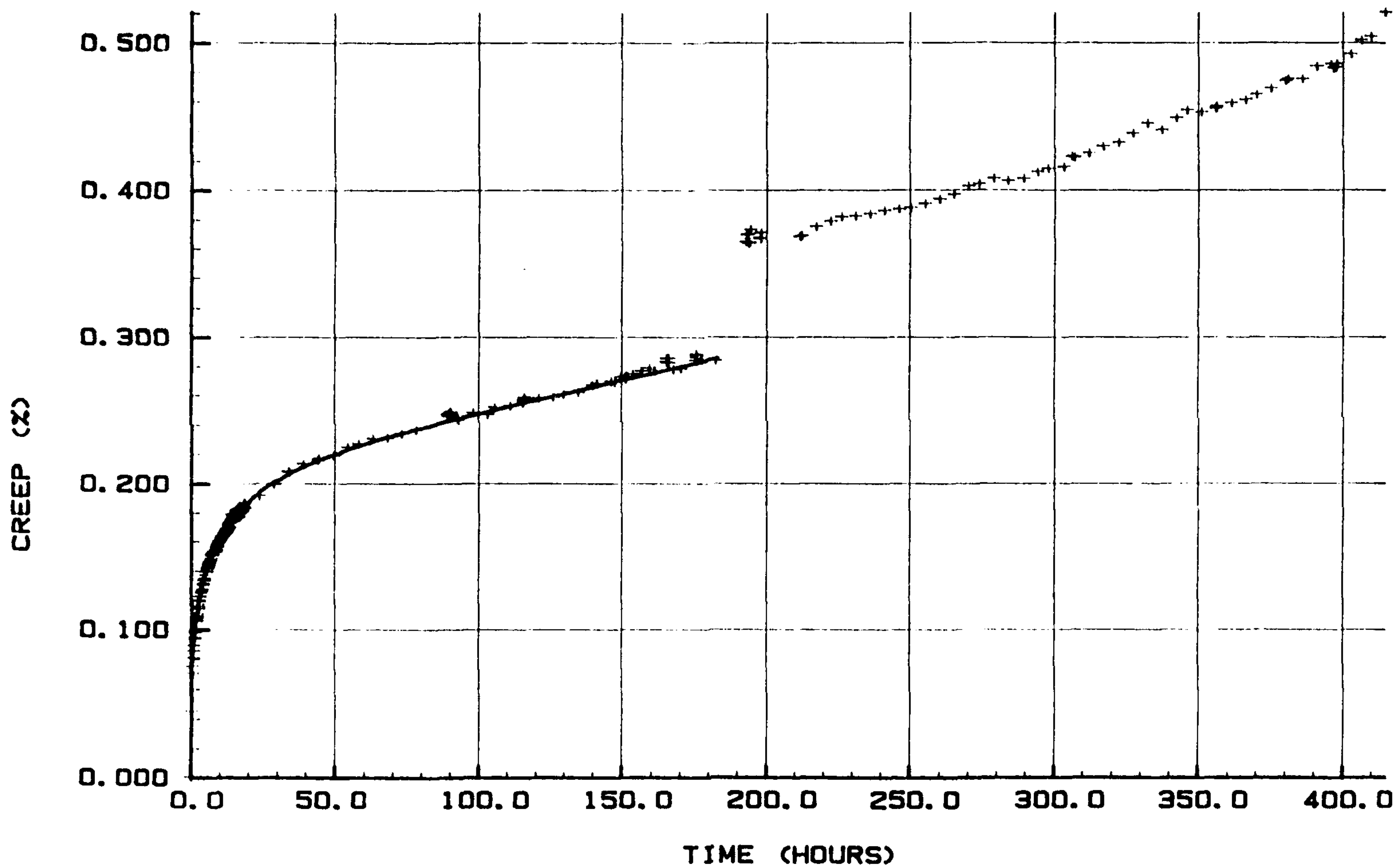
Edward Slattery
Supervisor

1393-46793 C53860 SPECIMEN NO 28L-1 649°C 628.8 MPa
.1%-0.84 HRS .2%-9.6 HRS



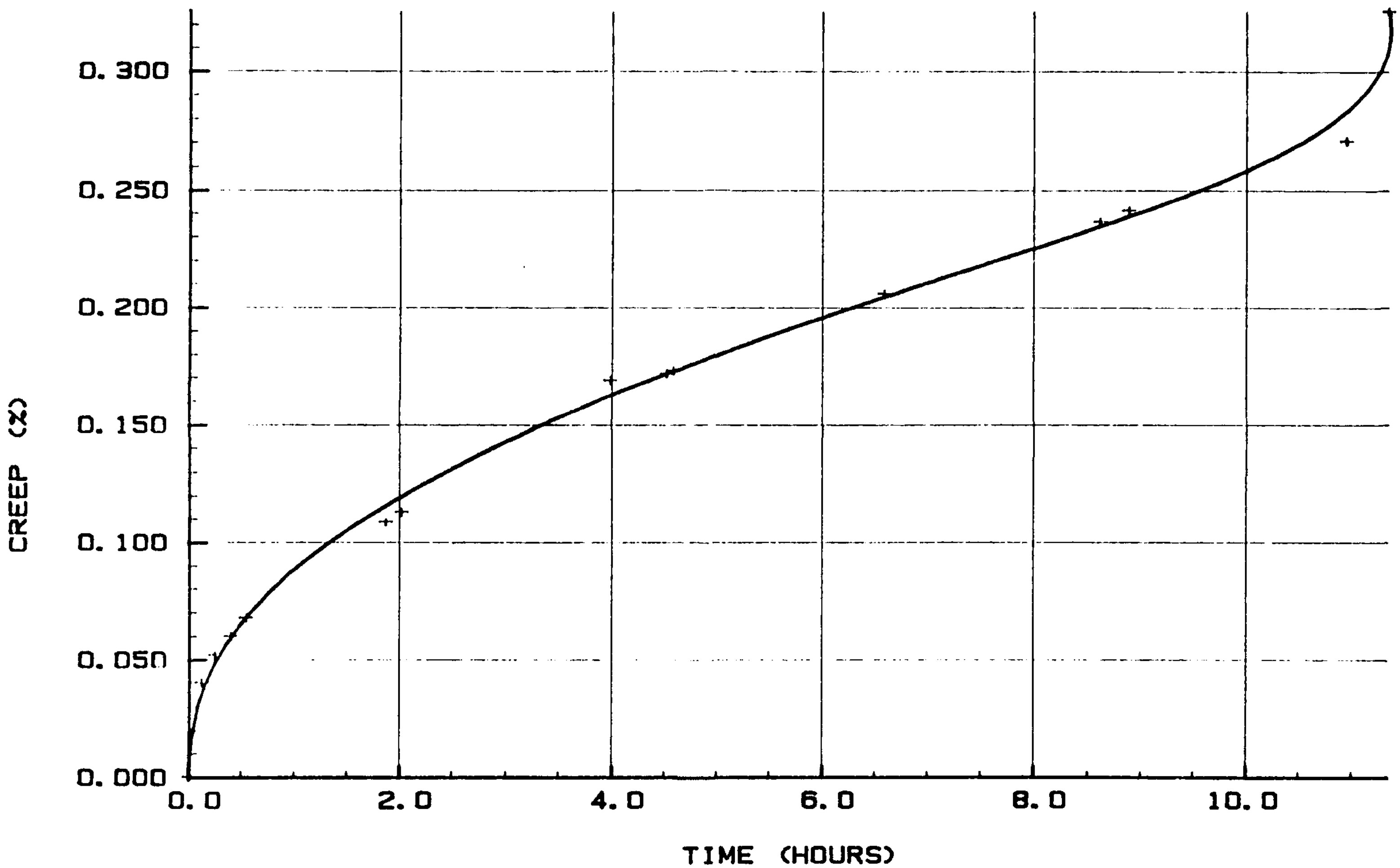
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C54001 SPECIMEN NO 30L-7 649°C 628.8 MPa
.1%-1.3 HRS .2%-28 HRS



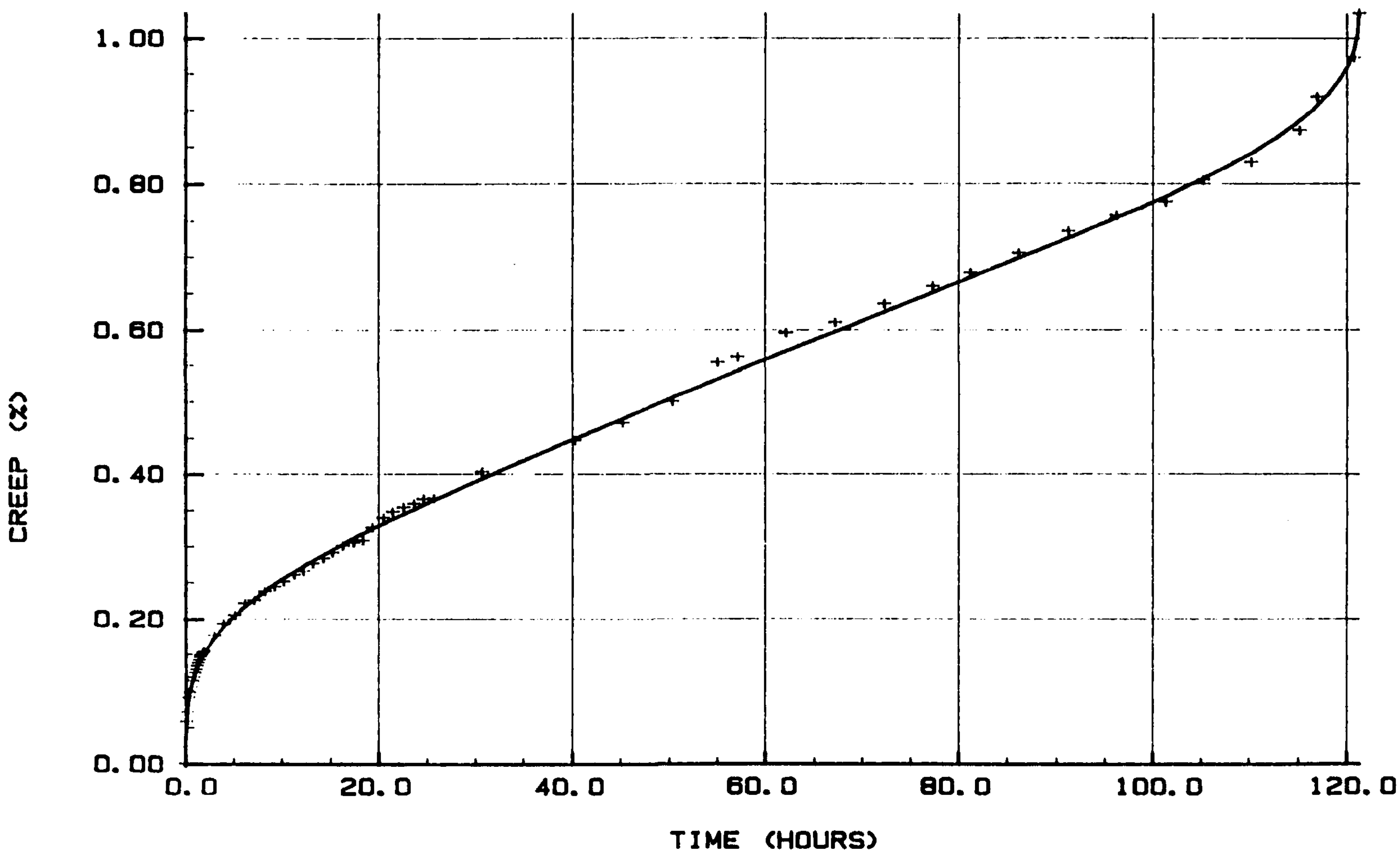
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C53994 SPECIMEN NO 28L-8 760°C 510.0 MPa



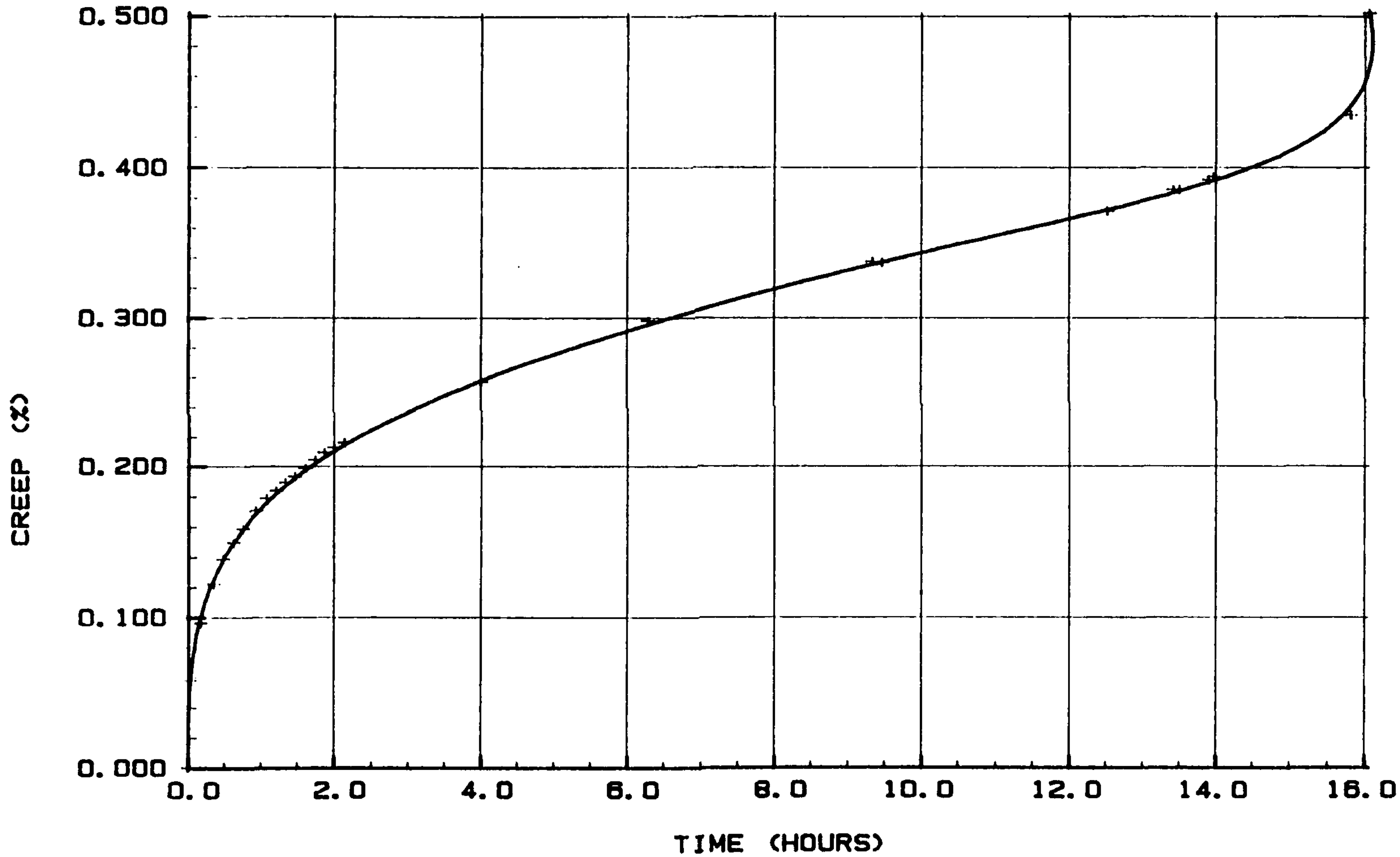
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793   C54016   SPECIMEN NO   30L-10   760°C   510.0 MPa
.1%-0.52 HRS   .2%-4.8 HRS   .5%-49 HRS   1.0%-121 HRS



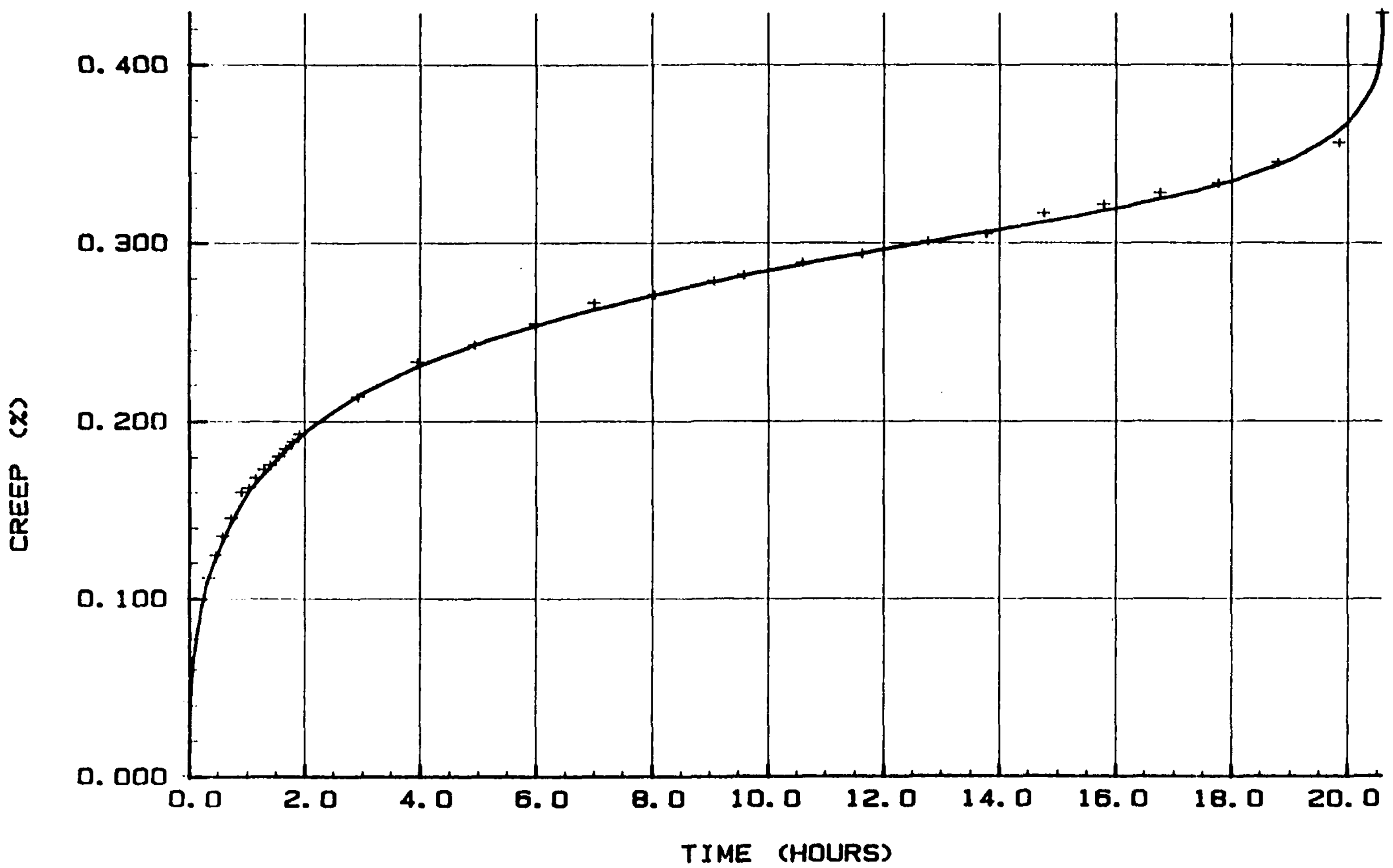
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45208 / (513) 271-5100

1393-46793 C54069 SPECIMEN NO 32-3 760°C 300.4 MPa
.1%-0.17 HRS .2%-1.7 HRS .5%-16.0 HRS



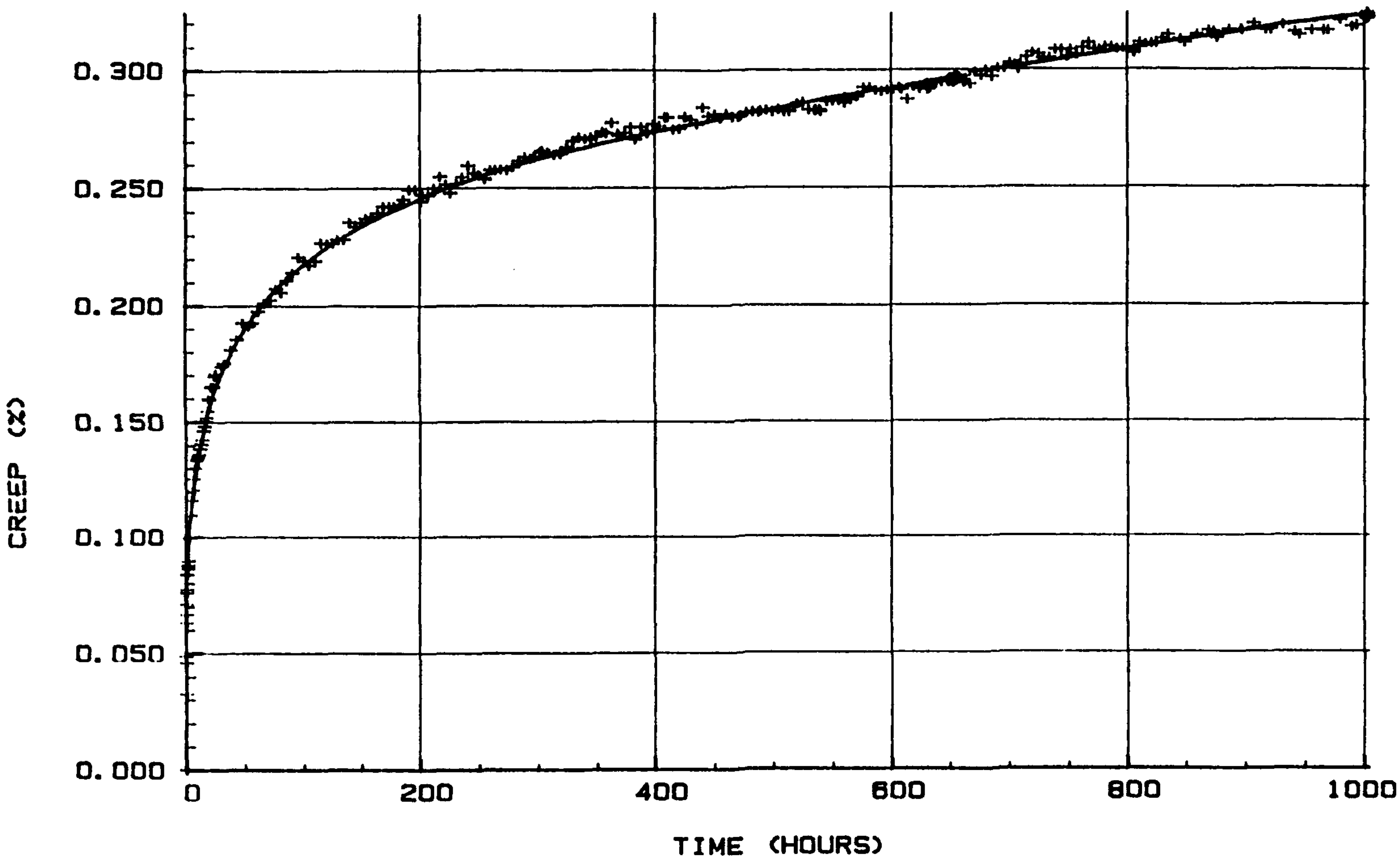
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C54085 SPECIMEN NO 33-1 760°C 300.4 MPa
.1%-0.25 HRS .2%-2.3 HRS



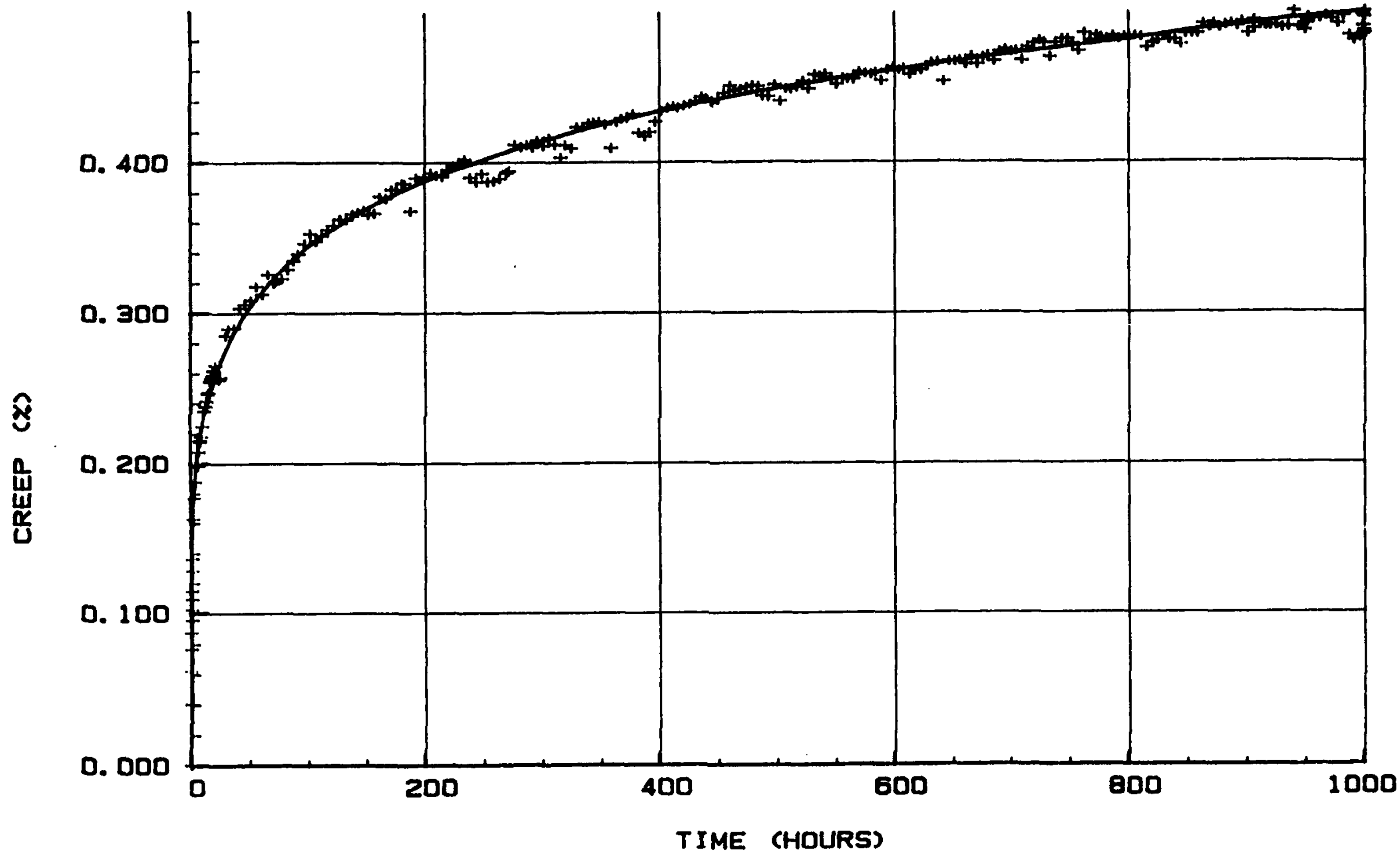
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C54130 SPECIMEN NO 32-10 760°C 188.6 MPa
.1%-3.0 HRS .2%-66 HRS



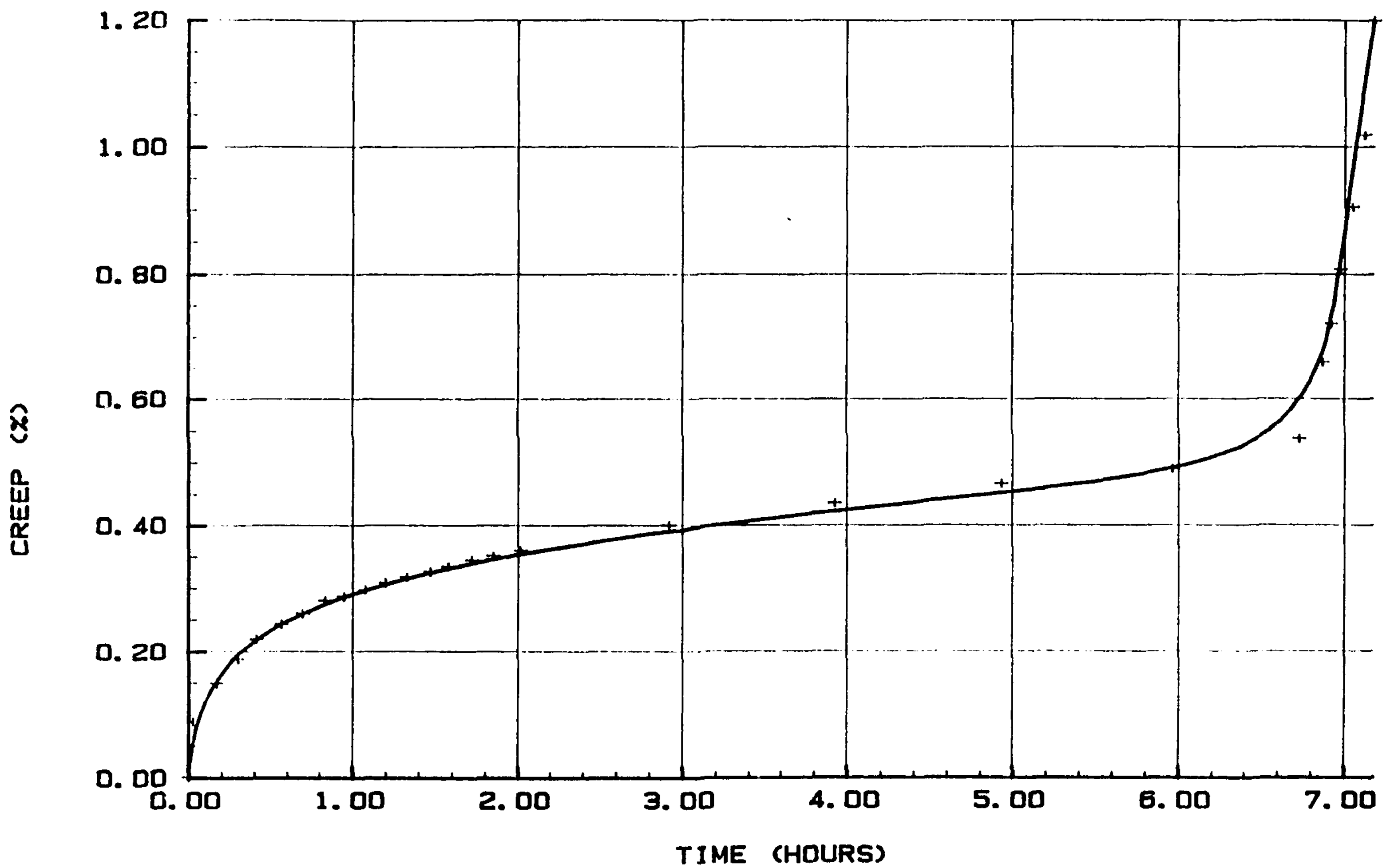
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C54255 SPECIMEN NO 33-2 760°C 188.6 MPa
.1%-0.53 HRS .2%-5.4 HRS



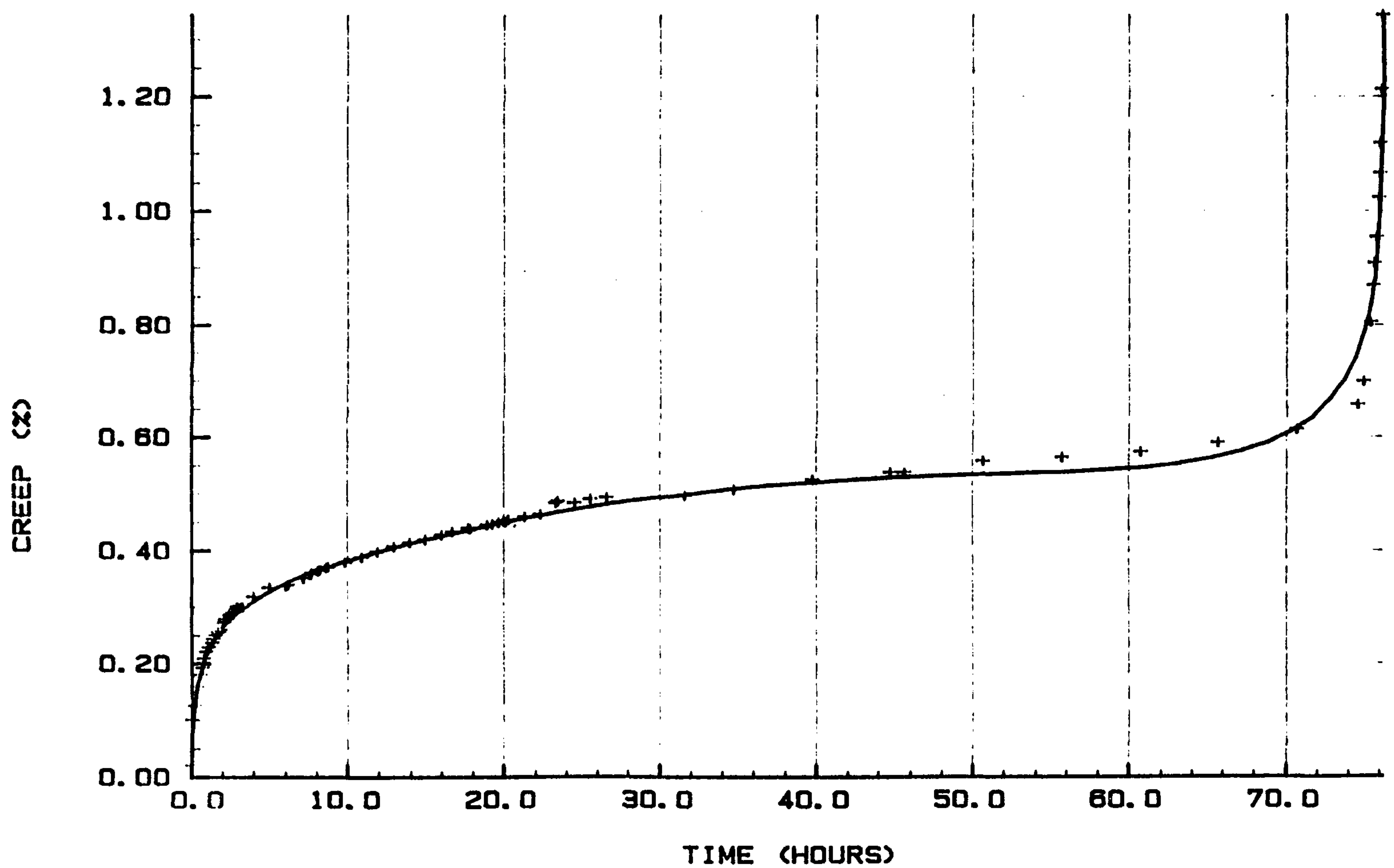
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C54093 SPECIMEN NO 35-1 760°C 188.6 MPa
.1%-0.07 HRS .2%-0.32 HRS .5%-6.1 HRS 1.0%-7.1 HRS



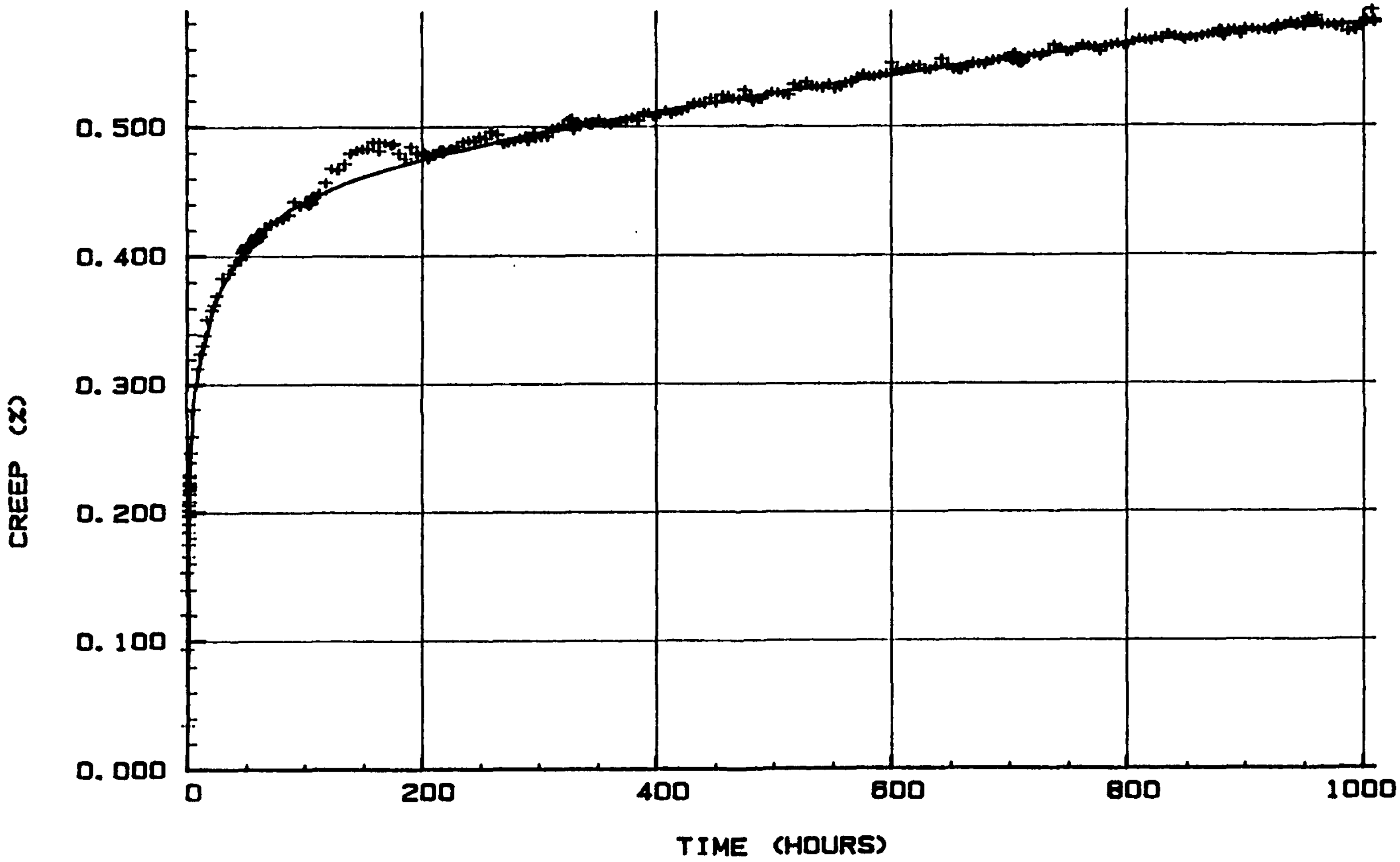
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46793 C54104 SPECIMEN NO 45-3 760°C 188.6 MPa
.1%-0.07 HRS .2%-0.73 HRS .5%-32 HRS 1.0%-76 HRS
0.021% PLASTIC CREEP ON LOADING



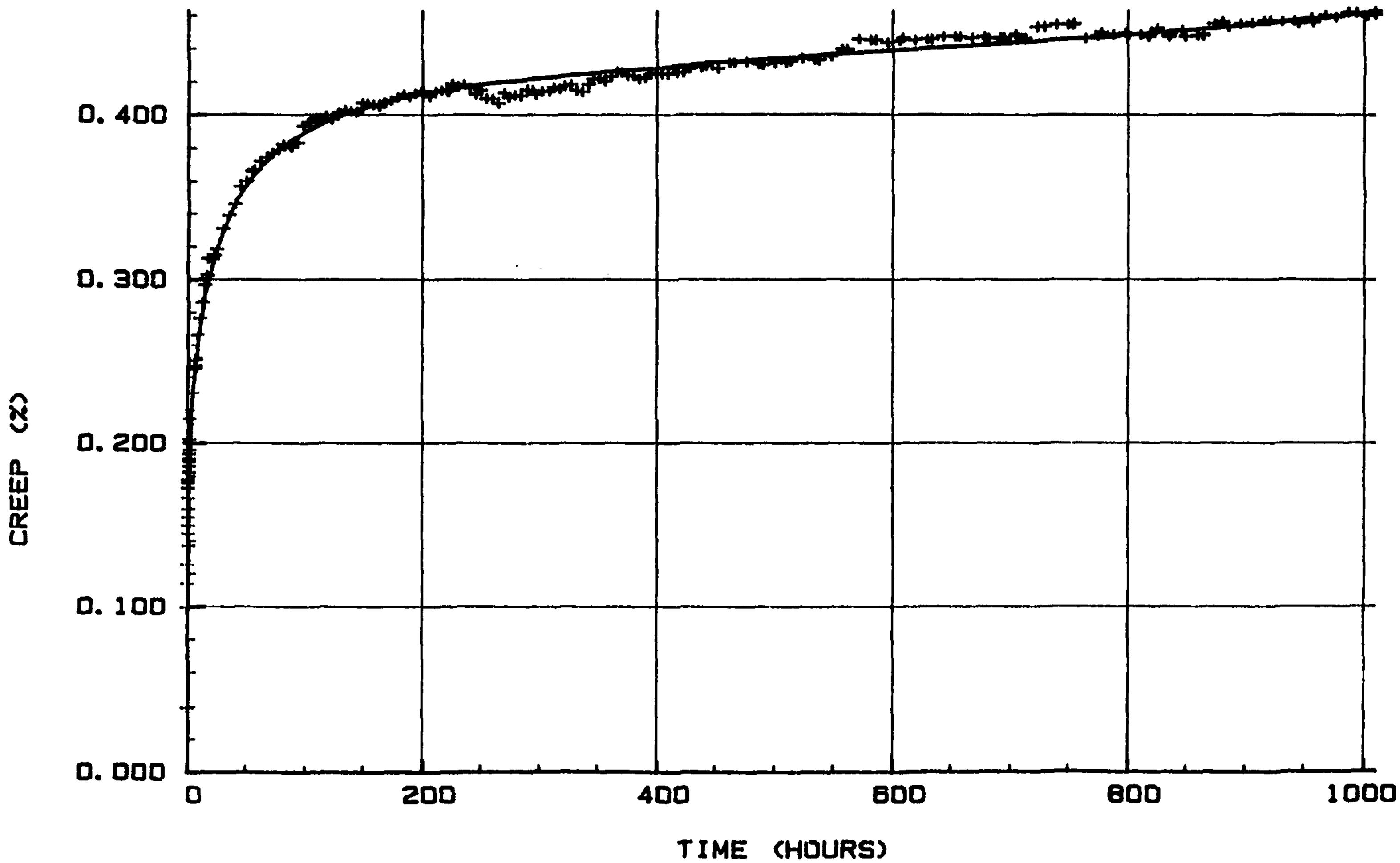
METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-46783 C54284 SPECIMEN NO 35-5 760°C 125.8 MPa
.1%-0.67 HRS .2%-1.5 HRS .5%-334 HRS
0.034% PLASTIC CREEP ON LOADING



METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / (513) 271-5100

1393-48793 C54283 SPECIMEN NO 45-5 760°C 125.8 MPa
.1%-0.38 HRS .2%-2.8 HRS
0.038% PLASTIC CREEP ON LOADING



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METCUT RESEARCH ASSOCIATES INC.

MATERIALS ENGINEERING DIVISION

3980 Rosslyn Drive, Cincinnati, Ohio 45209-1196 • Telephone 513-271-5100

Telex II: 810 461-2840 / EasyLink 6291-3788 FAX 513-271-9511

TO: Allison Gas Turbine
General Motors Corp.
Attn: Mary Lee Gambone W05
2001 South Tibbs Avenue
Indianapolis, IN 46241

NUMBER: 1393-46793-4
DATE: December 28, 1988
AUTHORIZATION: H828595
Page 1 of 1

PROJECT: Creep Rupture Testing of (3) 8-Ply SiC/Ti Composite Sheet Specimens Supplied and Identified by Allison Gas Turbine.

Nominal Gage Section: 1.5 x 7.6 x 29.7 mm Long

MRAI No.	Specimen Ident.	Temp. (°C)	Stress (MPa)	Time (hr) to % Creep of 0.1	0.2	0.5	1.0	Rupture Life (hours)	Elong. (%)
-	28T-1	-	-	-	-	-	-	(a)	-
C-53959	28T-2	760	27.9	-	-	-	-	(b)	-
-	28T-3	-	-	-	-	-	-	(c)	-

Notes: (a) Void test; broke while preparing for testing.
(b) Void test; broke while installing for test.
(c) Void; was found broken in envelope.

Louis J. Fritz, Manager
Creep, Stress Rupture & Tensile Testing
fw

Edward Slattery
Supervisor

APPENDIX B

Task II. Fatigue Crack Initiation Data

Material's Behavior Research Corporation

TABLE I

LCF SPECIMEN FINAL DATA SUMMARY: 04-17-89

AXIAL STRAIN MEASUREMENT AND CONTROL

Ti3AL/SCS-6

ALPHA, X 10^-6/DEG.C: 0
STRAIN R-RATIO: .1
TEMPERATURE, DEG.C: 26
WAVEFORM: TRIANGULAR
FREQUENCY Hz: .33
SPECIMEN DESIGN: LONGITUDINAL

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090A
P.O. No.: H838840

SPECIMEN ID	MACH	E AT TEST TEMP. GPa	STRN RNG%	1st CYCLE * STSS RNG MPa	1st CYCLE * MAX STSS MPa	MAX STRN %	Ni/2 (Nf/2 if no Ni) STSS RNG MPa	Ni/2 (Nf/2 if no Ni) MAX STSS MPa	ELAST STRN %	Ni CYCLES	N5 CYCLES	Nf CYCLES
A052-05	4	189	0.730	969	967	0.590	1282	1179	0.680	724	-0	724
A051-09	4	190	0.700	1166	1097	0.745	1151	1032	0.600	7019	-0	7019
A052-07	4	190	0.680	1243	1110	0.730	1172	1052	0.620	2950	-0	2950
A074-02	4	179	0.650	839	866	0.575	1011	895	0.560	8313	-0	8313
A052-02	4	176	0.645	1032	1003	0.681	764	607	0.430	-0	-0	104558
A071-02	4	181	0.645	854	854	0.535	749	588	0.410	-0	-0	107476
A074-03	4	190	0.620	918	904	0.580	1088	919	0.570	3611	-0	3611
A099-05	10	197	0.620	766	872	0.528	763	507	0.390	-0	64540	100002
A051-06	4	177	0.600	764	781	0.475	931	808	0.530	69320	44700	69320
A071-07	4	189	0.560	755	778	0.450	747	542	0.400	-0	86875	100607
A051-04	4	184	0.500	755	776	0.463	805	697	0.440	-0	91410	103692

* MAXIMUM STRAIN WAS NOT ACHIEVED IN THE FIRST CYCLE.
ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

A052-05 CRACK DESC.: OG;S;-0.56;MULTIPLE INITIATIONS;---;---;P
COMMENTS: LONGITUDINAL. STRAIN RANGE ATTAINED IN 25 CYCLES.

A051-09 CRACK DESC.: OG;S;+0.60;MULTIPLE INITIATIONS;---;---;P
COMMENTS: LONGITUDINAL. STRAIN RANGE ATTAINED IN 7 CYCLES.

A052-07 CRACK DESC.: OG;S;+0.35;MULTIPLE INITIATIONS;---;---;P
COMMENTS: LONGITUDINAL. STRAIN RANGE ATTAINED IN 7 CYCLES.

```
A074-02  CRACK DESC.: OG;S;-0.52;MULTIPLE INITIATIONS;---;---;P+S
         COMMENTS:    LONGITUDINAL.  STRAIN RANGE ATTAINED IN 25 CYCLES.
A052-02  CRACK DESC.: UNLOADED IN ONE PIECE.
         COMMENTS:    LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM
                      0.62% TO 0.725% AT CYCLE 6. STRAIN RANGE ESTABLISHED
                      AT CYCLE 7. STOPPED TEST - RUNOUT AT 104,558 CYCLES.
A071-02  CRACK DESC.: UNLOADED IN ONE PIECE
         COMMENTS:    LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM
                      0.53% TO 0.715% AT CYCLE 2. STRAIN RANGE ESTABLISHED
                      AT CYCLE 3. STOPPED TEST - RUNOUT AT 107,476 CYCLES.
A074-03  CRACK DESC.: OG;S;AT R.U.S.I.;MULTIPLE INITIATIONS;---;---;P
         COMMENTS:    LONGITUDINAL.  STRAIN RANGE ATTAINED IN 9 CYCLES.
A099-05  CRACK DESC.: UNLOADED IN ONE PIECE
         COMMENTS:    LONGITUDINAL. STRAIN POPPED OUT TO 0.85% ON FIRST
                      CYCLE. STRAIN RANGE ESTABLISHED AT 40 CYCLES.
                      STOPPED TEST - RUNOUT AT 100,002 CYCLES.
A051-06  CRACK DESC.: OG;S;+0.60;MULTIPLE INITIATIONS;---;--;P
         COMMENTS:    LONGITUDINAL.  STRAIN RANGE ATTAINED IN 60 CYCLES.
A071-07  CRACK DESC.: UNLOADED IN ONE PIECE
         COMMENTS:    LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM
                      0.45% TO 0.52% AT CYCLE 2. STRAIN RANGE ATTAINED IN
                      30 CYCLES.  STOPPED TEST - RUNOUT AT 100,607 CYCLES.
A051-04  CRACK DESC.: UNLOADED IN ONE PIECE
         COMMENTS:    LONGITUDINAL. STRAIN RANGE ATTAINED IN 6 CYCLES.
                      POSSIBLE INDICATION OF Ni AT CYCLE 79,230. STOPPED
                      TEST - RUNOUT AT 103,692 CYCLES.
```

Material's Behavior Research Corporation
TABLE II: STRESS-STRAIN DATA FOR FIRST LOAD-UP

TEMPERATURE: 26 DEG.C. R-RATIO: .1

	SPECIMEN A052-05		SPECIMEN A051-09		SPECIMEN A052-07		SPECIMEN A074-02	
	E @START=189 GPa		E @START=190 GPa		E @START=190 GPa		E @START=17[illegible] GPa	
	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN
PT.	MPa	%	MPa	%	MPa	%	MPa	%
1	114	0.060	138	0.070	128	0.070	96	0.060
2	226	0.120	271	0.140	260	0.140	186	0.110
3	349	0.180	398	0.210	390	0.210	293	0.170
4	461	0.240	523	0.280	520	0.280	385	0.220
5	574	0.300	636	0.350	644	0.350	493	0.280
6	677	0.360	726	0.420	742	0.420	581	0.330
7	763	0.420	810	0.490	831	0.490	666	0.390
8	846	0.480	887	0.560	914	0.560	731	0.440
9	919	0.540	964	0.630	1007	0.640	798	0.500
10	967	0.590	1097	0.745	1110	0.730	866	0.575

	SPECIMEN A052-02		SPECIMEN A071-02		SPECIMEN A074-03		SPECIMEN A099-05	
	E @START=176 GPa		E @START=181 GPa		E @START=190 GPa		E @START=197 GPa	
	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN
PT.	MPa	%	MPa	%	MPa	%	MPa	%
1	115	0.070	78	0.050	108	0.050	102	0.050
2	232	0.140	169	0.100	202	0.100	198	0.100
3	358	0.210	259	0.150	299	0.150	295	0.150
4	487	0.280	355	0.200	396	0.200	392	0.200
5	604	0.350	450	0.250	487	0.250	492	0.250
6	707	0.420	541	0.300	575	0.300	581	0.300
7	793	0.490	624	0.350	653	0.350	661	0.350
8	874	0.560	696	0.400	718	0.400	729	0.400
9	953	0.630	758	0.450	773	0.450	816	0.470
10	1003	0.681	854	0.535	904	0.580	872	0.528

	SPECIMEN A051-06		SPECIMEN A071-07		SPECIMEN A051-04	
	E @START=177 GPa		E @START=189 GPa		E @START=184 GPa	
	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN
PT.	MPa	%	MPa	%	MPa	%
1	88	0.050	78	0.040	77	0.040
2	174	0.100	149	0.080	154	0.080
3	269	0.150	246	0.130	227	0.120
4	362	0.200	341	0.180	307	0.160
5	454	0.250	419	0.220	379	0.200
6	543	0.300	494	0.260	449	0.240
7	625	0.350	582	0.310	519	0.280
8	696	0.400	660	0.360	589	0.320
9	751	0.440	717	0.400	648	0.360
10	781	0.475	778	0.450	776	0.463

Material's Behavior Research Corporation

TABLE I

LCF SPECIMEN FINAL DATA SUMMARY: 05-22-89

AXIAL STRAIN MEASUREMENT AND CONTROL

Ti3AL/SCS-6 ALLOY

ALPHA, X 10^-6/DEG.C: 0
STRAIN R-RATIO: .1
TEMPERATURE, DEG.C: 26
WAVEFORM: TRIANGULAR
FREQUENCY Hz: .33
SPECIMEN DESIGN: 45°

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090A
P.O. No.: H838840

				1st CYCLE *			Ni/2 (Nf/2 if no Ni)					
SPECIMEN ID	MACH	E AT TEST TEMP. GPa	STRN RNG%	STSS RNG MPa	MAX STSS MPa	MAX STRN %	STSS RNG MPa	MAX STSS MPa	ELAST STRN %	Ni CYCLES	N5 CYCLES	Nf CYCLES
A106-10	2	112	0.240	-0	-0	-.000	-0	-0	-.000	-0	-0	-0
A106-11	7	128	0.220	38	64	0.050	284	303	0.220	21	-0	24
A106-08	4	128	0.200	248	273	0.211	238	244	0.190	3180	3200	4220
A106-07b	1	138	0.180	229	256	0.188	240	273	0.170	2860	-0	2962
A106-09	2	128	0.160	205	224	0.172	205	212	0.160	-0	-0	100022
A106-07a	4	127	0.120	152	166	0.127	147	113	0.120	-0	-0	100124

* MAXIMUM STRAIN WAS NOT ACHIEVED IN THE FIRST CYCLE.

ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

A106-10 CRACK DESC.: AT R.U.S.I. - SEE COMMENTS
COMMENTS: 45 DEGREE ORIENTATION. SPECIMEN FAILED AT 0.253%, 293 MPa BEFORE REACHING DESIRED MAX STRAIN OF 0.267%.

A106-11 CRACK DESC.: IG;I & S;MULTI.INITS. ON MULTI.PLANES;---;---;P+S
COMMENTS: 45 DEGREE ORIENTATION. STRAIN RANGE ATTAINED IN 10 CYCLES.

A106-08 CRACK DESC.: OG;S;MULTIPLE INITIATIONS ON MULTIPLE PLANES;---;---;P+S
COMMENTS: 45 DEGREE ORIENTATION. STRAIN RANGE ATTAINED IN 6 CYCLES.

A106-07b CRACK DESC.: OG;S;+0.32;MULTI.INITS.;---;---;P+S
COMMENTS: 45 DEGREE ORIENTATION. PART 2 OF 2: RELOADED AFTER SPECIMEN WAS A RUNOUT AT 0.12% PER INSTRUCTIONS OF TEST ENGINEER. STRAIN RANGE ATTAINED IN 1 CYCLE.

A106-09	CRACK DESC.:	UNLOADED IN ONE PIECE
	COMMENTS:	45 DEGREE ORIENTATION. STRAIN RANGE ATTAINED IN 2 CYCLES. STOPPED TEST - RUNOUT AT 100,022 CYCLES.
A106-07a	CRACK DESC.:	UNLOADED IN ONE PIECE
	COMMENTS:	45 DEGREE ORIENTATION. PART 1 OF 1: STOPPED TEST - RUNOUT AT 100,124 CYCLES. RELOADED FOR PART 2 PER INSTRUCTIONS OF TEST ENGINEER. STRAIN RANGE ATTAINED IN 1 CYCLE.

Material's Behavior Research Corporation
TABLE II: STRESS-STRAIN DATA FOR FIRST LOAD-UP

TEMPERATURE: 26 DEG.C. R-RATIO: .1

PT.	SPECIMEN A106-10 E @START= 0 GPa STRESS MPa	STRAIN %	SPECIMEN A106-11 E @START= 0 GPa STRESS MPa	STRAIN %	SPECIMEN A106-08 E @START= 0 GPa STRESS MPa	STRAIN %	SPECIMEN A106-07b E @START= 0 GPa STRESS MPa	STRAIN %
1	23	0.020	6	0.005	27	0.020	29	0.020
2	46	0.040	13	0.010	52	0.040	58	0.040
3	70	0.060	19	0.015	78	0.060	85	0.060
4	95	0.080	26	0.020	104	0.080	112	0.080
5	120	0.100	32	0.025	130	0.100	139	0.100
6	145	0.120	39	0.030	156	0.120	167	0.120
7	157	0.130	45	0.035	181	0.140	193	0.140
8	169	0.140	51	0.040	207	0.160	221	0.160
9	182	0.150	58	0.045	240	0.185	233	0.170
10	195	0.161	64	0.050	273	0.211	256	0.188

PT.	SPECIMEN A106-09 E @START= 0 GPa STRESS MPa	STRAIN %	SPECIMEN A106-07a E @START= 0 GPa STRESS MPa	STRAIN %
1	14	0.010	39	0.030
2	29	0.020	51	0.040
3	54	0.040	64	0.050
4	79	0.060	77	0.060
5	104	0.080	90	0.070
6	130	0.100	103	0.080
7	156	0.120	116	0.090
8	181	0.140	129	0.100
9	209	0.160	142	0.110
10	224	0.172	166	0.127

Material's Behavior Research Corporation

TABLE I

LCF SPECIMEN FINAL DATA SUMMARY: 04-17-89

AXIAL STRAIN MEASUREMENT AND CONTROL

Ti3AL/SCS-6

ALPHA, X 10^-6/DEG.C: 0
STRAIN R-RATIO: .1
TEMPERATURE, DEG.C: 26
WAVEFORM: TRIANGULAR
FREQUENCY Hz: .33
SPECIMEN DESIGN: TRANSVERSE

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090A
P.O. No.: H838840

				1st CYCLE *			Ni/2 (Nf/2 if no Ni)					
SPECIMEN ID	MACH	E AT TEST TEMP. GPa	STRN RNG%	STSS RNG MPa	MAX STSS MPa	MAX STRN %	STSS RNG MPa	MAX STSS MPa	ELAST STRN %	Ni CYCLES	N5 CYCLES	Nf CYCLES
A056-03	5	143	0.150	-0	-0	-.000	-0	-0	-.000	-0	-0	-0
A057-06	13	138	0.140	253	212	0.156	187	207	0.140	157	-0	157
A056-11	5	157	0.130	189	200	0.132	198	206	0.130	566	-0	591
A058-05	13	132	0.120	159	170	0.133	157	136	0.120	28060	-0	31693
A062-06	3	133	0.120	110	133	0.099	161	159	0.120	-0	-0	100154
A057-05	2	126	0.110	136	149	0.118	133	149	0.110	-0	-0	100222
A056-05	4	131	0.100	84	93	0.074	126	165	0.100	41840	-0	42112
A057-03	1	135	0.100	135	144	0.110	133	131	0.100	-0	-0	100470
A057-01	7	143	0.090	125	146	0.100	119	95	0.080	-0	93665	100990
A056-07	5	143	0.070	102	108	0.078	98	103	0.070	-0	50715	101042

* MAXIMUM STRAIN WAS NOT ACHIEVED IN THE FIRST CYCLE.

ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

A056-03 CRACK DESC.: OG;S;-0.55;MULTIPLE INITIATIONS;---;---;P
COMMENTS: TRANSVERSE. STRAIN RANGE ATTAINED IN 2 CYCLES AND SPECIMEN FAILED IMMEDIATELY AFTERWARDS AT A MAX STRESS OF 232 MPa, MAX STRAIN OF 0.167%.

A057-06 CRACK DESC.: OG;S;+0.50;MULTIPLE INITIATIONS;---;---;P
COMMENTS: TRANSVERSE. STRAIN RANGE ATTAINED IN 7 CYCLES.

A056-11 CRACK DESC.: OG;I&S;-0.75;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: TRANSVERSE. STRAIN RANGE ESTABLISHED AT 55 CYCLES.

A058-05	CRACK DESC.:	OG;S;-0.40;MULTIPLE INITIATIONS;---;---;P+S
	COMMENTS:	TRANSVERSE. STRAIN RANGE ATTAINED ON 1st CYCLE.
A062-06	CRACK DESC.:	UNLOADED IN ONE PIECE
	COMMENTS:	TRANSVERSE. STRAIN RANGE ESTABLISHED AT 60 CYCLES. STOPPED TEST - RUNOUT AT 100,154 CYCLES.
A057-05	CRACK DESC.:	UNLOADED IN ONE PIECE.
	COMMENTS:	TRANSVERSE. STRAIN RANGE ATTAINED IN 2 CYCLES. STOPPED TEST - RUNOUT AT 100,222 CYCLES.
A056-05	CRACK DESC.:	OG;S;+0.30;---;0.00;0.12;P+S
	COMMENTS:	TRANSVERSE. STRAIN RANGE ATTAINED IN 18 CYCLES. ONE HALF OF SPECIMEN WAS BROKEN (NOW IN THREE PIECES) WHILE UNLOADING FROM MACHINE AFTER FAILURE.
A057-03	CRACK DESC.:	UNLOADED IN ONE PIECE
	COMMENTS:	TRANSVERSE. EXTENSOMETER SLIPPED ON START-UP APPLYING 109 MPa IN COMPRESSIVE STRESS, BUT DID NOT EXCEED ELASTIC LIMIT. STRAIN RANGE ATTAINED IN 2 CYCLES. STOPPED TEST - RUNOUT AT 100,470 CYCLES.
A057-01	CRACK DESC.:	UNLOADED IN ONE PIECE.
	COMMENTS:	TRANSVERSE. STRAIN RANGE ATTAINED ON 1st CYCLE. STOPPED TEST - RUNOUT AT 100,990 CYCLES.
A056-07	CRACK DESC.:	UNLOADED IN ONE PIECE
	COMMENTS:	TRANSVERSE. STRAIN RANGE ATTAINED ON 1st CYCLE. STOPPED TEST - RUNOUT AT 101,042 CYCLES.

Material's Behavior Research Corporation
TABLE II: STRESS-STRAIN DATA FOR FIRST LOAD-UP

TEMPERATURE: 26 DEG.C. R-RATIO: .1

	SPECIMEN A056-03		SPECIMEN A057-06		SPECIMEN A056-11		SPECIMEN A058-05	
	E @START=143 GPa		E @START=138 GPa		E @START=157 GPa		E @START=132 GPa	
PT.	STRESS MPa	STRAIN %	STRESS MPa	STRAIN %	STRESS MPa	STRAIN %	STRESS MPa	STRAIN %
1	18	0.010	14	0.010	15	0.010	13	0.010
2	33	0.020	42	0.030	31	0.020	26	0.020
3	48	0.030	56	0.040	47	0.030	39	0.030
4	62	0.040	83	0.060	64	0.040	51	0.040
5	77	0.050	97	0.070	94	0.060	63	0.050
6	91	0.060	125	0.090	118	0.075	77	0.060
7	104	0.070	139	0.100	140	0.090	103	0.080
8	134	0.090	166	0.120	162	0.105	130	0.100
9	146	0.100	180	0.130	184	0.120	156	0.120
10	181	0.125	212	0.156	200	0.132	170	0.133

	SPECIMEN A062-06		SPECIMEN A057-05		SPECIMEN A056-05		SPECIMEN A057-03	
	E @START=133 GPa		E @START=126 GPa		E @START=131 GPa		E @START=135 GPa	
PT.	STRESS MPa	STRAIN %	STRESS MPa	STRAIN %	STRESS MPa	STRAIN %	STRESS MPa	STRAIN %
1	16	0.010	14	0.010	14	0.010	11	0.010
2	33	0.020	27	0.020	25	0.020	26	0.020
3	45	0.030	39	0.030	38	0.030	38	0.030
4	58	0.040	51	0.040	51	0.040	51	0.040
5	71	0.050	64	0.050	65	0.050	64	0.050
6	85	0.060	76	0.060	72	0.055	79	0.060
7	98	0.070	89	0.070	77	0.060	92	0.070
8	112	0.080	102	0.080	83	0.065	105	0.080
9	125	0.090	127	0.100	90	0.070	134	0.100
10	133	0.099	149	0.118	93	0.074	144	0.110

	SPECIMEN A057-01		SPECIMEN A056-07	
	E @START=143 GPa		E @START=143 GPa	
PT.	STRESS MPa	STRAIN %	STRESS MPa	STRAIN %
1	19	0.010	16	0.010
2	33	0.020	24	0.015
3	46	0.030	38	0.025
4	61	0.040	53	0.035
5	76	0.050	59	0.040
6	89	0.060	66	0.045
7	103	0.070	80	0.055
8	118	0.080	93	0.065
9	133	0.090	101	0.070
10	146	0.100	[illegible]	0.078

Material's Behavior Research Corporation

TABLE I

LCF SPECIMEN FINAL DATA SUMMARY: 04-17-89

AXIAL STRAIN MEASUREMENT AND CONTROL

Ti3AL/SCS-6

ALPHA, X 10^-6/DEG.C: 6
STRAIN R-RATIO: .1
TEMPERATURE, DEG.C: 316
WAVEFORM: TRIANGULAR
FREQUENCY Hz: .33
SPECIMEN DESIGN: LONGITUDINAL

AGT Engineer: GAMBONE
Vendor phone: (513)248-1722
MBRC Job No.: 010-090A
P.O. No.: H838840

				1st CYCLE *			Ni/2 (Nf/2 if no Ni)					
SPECIMEN ID	MACH	E AT TEST TEMP. GPa	STRN RNG%	STSS RNG MPa	MAX STSS MPa	MAX STRN %	STSS RNG MPa	MAX STSS MPa	ELAST STRN %	Ni CYCLES	N5 CYCLES	Nf CYCLES
A071-05	4	193	0.750	1044	1042	0.670	-0	-0	-.000	-0	-0	45
A071-10	5	176	0.750	840	885	0.565	-0	-0	-.000	0	-0	-0
A052-06	5	188	0.700	922	960	0.620	1141	960	0.610	16810	20710	21817
A071-03	4	185	0.650	919	948	0.610	1051	893	0.570	36411	-0	37988
A052-04	3	185	0.620	915	912	0.567	1017	944	0.550	33560	46116	46120
A097-05	2	187	0.580	712	781	0.440	949	855	0.510	60653	58440	60653

* MAXIMUM STRAIN WAS NOT ACHIEVED IN THE FIRST CYCLE.

ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

A071-05 CRACK DESC.: OG;I & S;-0.42;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: LONGITUDINAL. RT E=198 GPa. STRAIN RANGE ATTAINED IN 43 CYCLES. FAILED 2 CYCLES AFTER REACHING STRAIN RANGE AT 1231 MPa.

A071-10 CRACK DESC.: SEE COMMENTS
COMMENTS: LONGITUDINAL. RT E = 181 GPa. SPECIMEN SLIPPED FROM GRIPS BEFORE ATTAINING STRAIN RANGE; OVERLOADED DURING RESTART. VOID TEST.

A052-06 CRACK DESC.: IG;S;+0.12;---;0.00;0.12;P+S
COMMENTS: LONGITUDINAL. RT E = 196 GPa. STRAIN RANGE ATTAINED IN 45 CYCLES.

A071-03 CRACK DESC.: IG;I&S;-0.23;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: LONGITUDINAL. RT E = 191 GPa. STRAIN RANGE ATTAINED IN 8 CYCLES.

A052-04	CRACK DESC.:	IG;S;+0.08;MULTIPLE INITIATIONS;---;---;P+S
	COMMENTS:	LONGITUDINAL. RT E = 190 GPa. STRAIN RANGE ATTAINED IN 35 CYCLES.
A097-05	CRACK DESC.:	IG;S;MULTIPLE INITIATIONS ON MULTIPLE PLANES;---;---;P+S
	COMMENTS:	LONGITUDINAL. RT E = 195 GPa. STRAIN RANGE ESTABLISHED AT 160 CYCLES.

Material's Behavior Researcn Corporation
TABLE II: STRESS-STRAIN DATA FOR FIRST LOAD-UP

TEMPERATURE: 316 DEG.C. R-RATIO: .1

PT.	SPECIMEN A071-05 E @START=193 GPa STRESS MPa	STRAIN %	SPECIMEN A071-10 E @START=176 GPa STRESS MPa	STRAIN %	SPECIMEN A052-06 E @START=188 GPa STRESS MPa	STRAIN %	SPECIMEN A071-03 E @START=185 GPa STRESS MPa	STRAIN %
1	158	0.080	171	0.100	116	0.060	116	0.060
2	314	0.160	262	0.150	229	0.120	229	0.120
3	430	0.220	352	0.200	341	0.180	343	0.180
4	550	0.280	444	0.250	456	0.240	456	0.240
5	648	0.340	533	0.300	565	0.300	565	0.300
6	721	0.400	619	0.350	654	0.360	656	0.360
7	796	0.460	689	0.400	728	0.420	729	0.420
8	882	0.530	748	0.450	804	0.480	798	0.480
9	971	0.600	820	0.510	877	0.540	869	0.540
10	1042	0.670	885	0.565	960	0.620	948	0.610

PT.	SPECIMEN A052-04 E @START=185 GPa STRESS MPa	STRAIN %	SPECIMEN A097-05 E @START=187 GPa STRESS MPa	STRAIN %
1	96	0.060	125	0.060
2	219	0.130	234	0.120
3	318	0.180	310	0.160
4	433	0.240	385	0.200
5	529	0.290	460	0.240
6	635	0.350	537	0.280
7	698	0.400	609	0.320
8	777	0.460	685	0.360
9	843	0.510	740	0.400
10	912	0.567	781	0.440

Material's Behavior Research Corporation

TABLE I

LCF SPECIMEN FINAL DATA SUMMARY: 04-17-89

AXIAL STRAIN MEASUREMENT AND CONTROL

Ti3AL/SCS-6

ALPHA, X 10^-6/DEG.C: 12.3
STRAIN R-RATIO: .1
TEMPERATURE, DEG.C: 649
WAVEFORM: TRIANGULAR
FREQUENCY Hz: .33
SPECIMEN DESIGN: LONGITUDINAL

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090A
P.O. No.: H838840

				1st CYCLE*			Ni/2 (Nf/2 if no Ni)					
SPECIMEN ID	MACH	E AT TEST TEMP. GPa	STRN RNG%	STSS RNG MPa	MAX STSS MPa	MAX STRN %	STSS RNG MPa	MAX STSS MPa	ELAST STRN %	Ni CYCLES	N5 CYCLES	Nf CYCLES
A052-08	4	152	0.650	949	992	0.720	935	900	0.620	953	-0	953
A052-10	11	-0	0.600	-0	-0	-.000	-0	-0	-.000	-0	-0	-0
A071-09	10	151	0.600	690	746	0.498	873	759	0.580	1700	-0	1986
A102-05	1	183	0.550	869	927	0.553	946	933	0.520	480	-0	52[illegible]
A071-04	5	148	0.500	607	688	0.468	719	688	0.490	-0	-0	9794
A060-09	11	170	0.480	730	783	0.492	791	764	0.470	8255	8920	13343
A054-04	4	166	0.450	628	687	0.422	740	729	0.450	4700	5050	5077
A054-05	5	172	0.450	595	675	0.392	765	724	0.440	5570	-0	5595
A060-10	5	189	0.430	476	600	0.330	750	717	0.400	8180	8271	8271
A105-05	9	161	0.420	591	651	0.411	659	619	0.410	17800	17240	19052
A071-01	4	157	0.400	505	546	0.370	534	472	0.340	69020	69040	100464
A054-03	13	-0	-.000	-0	-0	-.000	-0	-0	-.000	-0	-0	-0

* MAXIMUM STRAIN WAS NOT ACHIEVED IN THE FIRST CYCLE.

A052-08	CRACK DESC.:	IG;S;+0.35;MULTIPLE INITIATIONS;---;---;P+S
	COMMENTS:	LONGITUDINAL. RT E = 177 GPa. STRAIN RANGE ATTAINED IN 4 CYCLES.
A052-10	CRACK DESC.:	SYSTEM INSTABILITY PULLED SPECIMEN IN TWO DURING START UP
	COMMENTS:	LONGITUDINAL. VOID TEST.
A071-09	CRACK DESC.:	OG;S;+0.30;MULTIPLE INITIATIONS;---;---;P+S
	COMMENTS:	LONGITUDINAL. RT E = 174 GPa. STRAIN RANGE ATTAINED IN 10 CYCLES. STRAIN POPPED OUT TO 0.78% SHORTLY AFTER TEST BEGAN.
A102-05	CRACK DESC.:	OG;S;+0.32;MULTIPLE INITIATIONS;---;---;P+S
	COMMENTS:	LONGITUDINAL. RT E = 210 GPa. STRAIN RANGE ATTAINED AT 8 CYCLES.
A071-04	CRACK DESC.:	OG;S;MULTIPLE INITIATIONS ON MULTIPLE PLANES;---;---;P+S
	COMMENTS:	LONGITUDINAL. RT E = 168 GPa. STRAIN RANGE ATTAINED IN 22 CYCLES. Ni & N5 ARE NOT AVAILABLE DUE TO DISK ERROR.
A060-09	CRACK DESC.:	IG;S;MULTIPLE INITIATIONS;---;---;P+S
	COMMENTS:	LONGITUDINAL. RT E = 194 GPa. STRAIN RANGE ATTAINED IN 4 CYCLES.
A054-04	CRACK DESC.:	OG;S;-0.35;MULTIPLE INITIATIONS;---;---;P+S
	COMMENTS:	LONGITUDINAL. RT E = 189 GPa. STRAIN RANGE ATTAINED IN 8 CYCLES.
A054-05	CRACK DESC.:	OG;S;+0.55;MULTIPLE INITIATIONS;---;---;P
	COMMENTS:	LONGITUDINAL. RT E = 200 GPa. STRAIN RANGE ATTAINED IN 55 CYCLES.
A060-10	CRACK DESC.:	OG;S;MULTIPLE INITIATIONS ON MULTIPLE PLANES;---;---;P+S
	COMMENTS:	LONGITUDINAL. RT E = 209 GPa. STRAIN RANGE ATTAINED IN 25 CYCLES.
A105-05	CRACK DESC.:	OG;S;@R.U.S.I.;MULTI.INITS. ON MULTI.PLANES;---;---;P+S
	COMMENTS:	LONGITUDINAL. RT E = 190 GPa. STRAIN RANGE ATTAINED IN 11 CYCLES.
A071-01	CRACK DESC.:	UNLOADED IN ONE PIECE
	COMMENTS:	LONGITUDINAL. RT E = 180 GPa. STRAIN RANGE ATTAINED IN 9 CYCLES. STOPPED TEST - RUNOUT AT 100,464 CYCLES.
A054-03	CRACK DESC.:	SYSTEM INSTABILITY PULLED SPECIMEN IN TWO PIECES AT START
	COMMENTS:	LONGITUDINAL. VOID TEST.

Material's Behavior Research Corporation
TABLE II: STRESS-STRAIN DATA FOR FIRST LOAD-UP

TEMPERATURE: 649 DEG.C. R-RATIO: .1

	SPECIMEN A052-08		SPECIMEN A052-10		SPECIMEN A071-09		SPECIMEN A102-05	
	E @START=152 GPa		E @START= N/A		E @START=151 GPa		E @START=183 GPa	
	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN
PT.	MPa	%	MPa	%	MPa	%	MPa	%
1	97	0.070	-0	-0.000	77	0.050	113	0.050
2	198	0.140	-0	-0.000	155	0.100	208	0.100
3	301	0.210	-0	-0.000	232	0.150	297	0.150
4	407	0.280	-0	-0.000	309	0.200	384	0.200
5	513	0.350	-0	-0.000	387	0.250	476	0.250
6	614	0.420	-0	-0.000	464	0.300	559	0.300
7	712	0.490	-0	-0.000	534	0.350	641	0.350
8	804	0.560	-0	-0.000	612	0.400	720	0.400
9	891	0.630	-0	-0.000	689	0.450	841	0.480
10	992	0.700	-0	-0.000	746	0.498	927	0.553

	SPECIMEN A071-04		SPECIMEN A060-09		SPECIMEN A054-04		SPECIMEN A054-05	
	E @START=148 GPa		E @START=170 GPa		E @START=166 GPa		E @START=172 GPa	
	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN
PT.	MPa	%	MPa	%	MPa	%	MPa	%
1	82	0.060	82	0.050	81	0.060	71	0.040
2	140	0.100	167	0.100	146	0.100	136	0.080
3	209	0.150	254	0.150	213	0.140	207	0.120
4	272	0.190	337	0.200	281	0.180	278	0.160
5	349	0.240	414	0.250	347	0.220	348	0.200
6	409	0.280	496	0.300	414	0.260	418	0.240
7	473	0.320	545	0.350	486	0.300	488	0.280
8	547	0.370	650	0.400	554	0.340	558	0.320
9	607	0.410	725	0.450	620	0.380	625	0.360
10	688	0.468	783	0.492	687	0.422	675	0.392

	SPECIMEN A060-10		SPECIMEN A105-05		SPECIMEN A071-01		SPECIMEN A054-03	
	E @START=189 GPa		E @START=161 GPa		E @START=157 GPa		E @START= 0 GPa	
	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN
PT.	MPa	%	MPa	%	MPa	%	MPa	%
1	69	0.030	73	0.040	55	0.040	-0	-0.000
2	119	0.060	137	0.080	109	0.080	-0	-0.000
3	156	0.080	201	0.120	165	0.120	-0	-0.000
4	237	0.120	265	0.160	230	0.160	-0	-0.000
5	308	0.160	330	0.200	289	0.200	-0	-0.000
6	380	0.200	393	0.240	355	0.240	-0	-0.000
7	450	0.240	456	0.280	416	0.280	-0	-0.000
8	521	0.280	519	0.320	479	0.320	-0	-0.000
9	575	0.310	580	0.360	525	0.350	-0	-0.000
10	600	0.330	651	0.411	546	0.370	-0	-0.000

Ma'terial's Behavior Research Corporation

TABLE I

LCF SPECIMEN FINAL DATA SUMMARY: 05-22-89

AXIAL STRAIN MEASUREMENT AND CONTROL

Ti3AL/SCS-6 ALLOY

ALPHA, X 10^-6/DEG.C: 12.3
STRAIN R-RATIO: .1
TEMPERATURE, DEG.C: 649
WAVEFORM: TRIANGULAR
FREQUENCY Hz: .33
SPECIMEN DESIGN: 45°

AGT Engineer: GAMBONE
Vendor phone: (513)248-_722
MBRC Job No.: 010-090A
P.O. No.: H838840

SPECIMEN ID	MACH	E AT TEST TEMP. GPa	STRN RNG%	1st CYCLE* STSS RNG MPa	1st CYCLE* MAX STSS MPa	1st CYCLE* MAX STRN %	Ni/2 (Nf/2 if no Ni) STSS RNG MPa	Ni/2 (Nf/2 if no Ni) MAX STSS MPa	Ni/2 (Nf/2 if no Ni) ELAST STRN %	Ni CYCLES	N5 CYCLES	Nf CYCLES
A106-04	2	77	0.600	250	197	0.650	192	122	0.250	1340	1310	1868
A106-05	7	86	0.550	222	194	0.560	199	131	0.230	860	860	1066
A106-06	1	90	0.500	234	200	0.520	188	126	0.210	2050	-0	2131
A106-03	2	75	0.400	163	157	0.356	96	49	0.130	-0	52460	100000
A106-02	2	81	0.300	126	123	0.241	101	54	0.120	-0	55100	100438

* MAXIMUM STRAIN WAS NOT ACHIEVED IN THE FIRST CYCLE.

ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

A106-04 CRACK DESC.: IG;S;MULTI.INITS. ON MULTI.PLANES;---;---;P+S
COMMENTS: 45 DEGREE ORIENTATION. RT E = 118 GPa. STRAIN RANGE ATTAINED IN 8 CYCLES.

A106-05 CRACK DESC.: IG;S;+0.10;MULTI.INITS.;---;---;P+S
COMMENTS: 45 DEGREE ORIENTATION. RT E = 123 GPa. STRAIN RANGE ATTAINED IN 14 CYCLES.

A106-06 CRACK DESC.: OG;S;-0.36;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: 45 DEGREE ORIENTATION. RT E = 127 GPa. STRAIN RANGE ATTAINED IN 5 CYCLES.

A106-03 CRACK DESC.: IN ONE PIECE AT END OF TEST BUT BROKEN WHILE UNLOADING
COMMENTS: 45 DEGREE ORIENTATION. RT E = 108 GPa. STRAIN RANGE ATTAINED IN 8 CYCLES. STOPPED TEST - RUNOUT AT 100,000 CYCLES.

A106-02 CRACK DESC.: UNLOADED IN ONE PIECE
COMMENTS: 45 DEGREE ORIENTATION. RT E = 124 GPa. STRAIN RANGE ATTAINED IN 17 CYCLES. STOPPED TEST - RUNOUT AT 100,438 CYCLES.

Material's Behavior Research Corporation
TABLE II: STRESS-STRAIN DATA FOR FIRST LOAD-UP

TEMPERATURE: 649 DEG.C. R-RATIO: .1

PT.	SPECIMEN A106-04 E @START= 0 CPa STRESS MPa	STRAIN %	SPECIMEN A106-05 E @START= 0 GPa STRESS MPa	STRAIN %	SPECIMEN A106-06 E @START= 0 GPa STRESS MPa	STRAIN %	SPECIMEN A106-03 E @START= 0 GPa STRESS MPa	STRAIN %
1	36	0.050	35	0.040	54	0.060	33	0.040
2	65	0.100	68	0.090	83	0.110	60	0.080
3	85	0.150	88	0.140	101	0.160	73	0.110
4	102	0.200	109	0.200	118	0.210	88	0.150
5	136	0.300	127	0.250	135	0.260	98	0.180
6	157	0.350	150	0.320	152	0.310	111	0.220
7	170	0.400	170	0.380	168	0.360	122	0.250
8	184	0.450	187	0.450	183	0.410	133	0.280
9	191	0.500	193	0.510	194	0.460	147	0.320
10	197	0.650	194	0.560	200	0.520	157	0.356

PT.	SPECIMEN A106-02 E @START= 0 GPa STRESS MPa	STRAIN %
1	24	0.030
2	49	0.060
3	63	0.080
4	74	0.100
5	83	0.120
6	92	0.140
7	98	0.160
8	105	0.180
9	114	0.210
10	123	0.241

Material's Behavior Research Corporation

TABLE 1

LCF SPECIMEN FINAL DATA SUMMARY: 04-17-89

AXIAL STRAIN MEASUREMENT AND CONTROL

Ti3AL/SCS 6

ALPHA, X 10^-6/DEG.C: 12.3
STRAIN R-RATIO: .1
TEMPERATURE, DEG.C: 649
WAVEFORM: TRIANGULAR
FREQUENCY Hz: .33
SPECIMEN DESIGN: TRANSVERSE

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090A
P.O. No.: H838840

SPECIMEN ID	MACH	E AT TEST TEMP. GPa	STRN RNG%	1st CYCLE* STSS RNG MPa	1st CYCLE* MAX STSS MPa	1st CYCLE* MAX STRN %	Ni/2 (Nf/2 if no Ni) STSS RNG MPa	Ni/2 (Nf/2 if no Ni) MAX STSS MPa	Ni/2 (Nf/2 if no Ni) ELAST STRN %	Ni CYCLES	N5 CYCLES	Nf CYCLES
A057-04	4	92	0.300	79	101	0.210	124	91	0.130	915	-0	999
A082-03	1	92	0.260	117	120	0.296	69	37	0.080	-0	53110	100000
A057-08	4	109	0.250	102	112	0.235	116	81	0.110	1390	-0	1435
A056-06	7	101	0.240	70	86	0.146	121	77	0.120	2330	2540	2707
A057-02	7	105	0.230	87	91	0.184	118	64	0.110	4240	-0	4326
A056-08	7	133	0.220	71	84	0.141	129	77	0.100	865	865	1000
A082-10	4	124	0.220	94	99	0.206	67	33	0.050	-0	54900	100000
A056-04	7	-0	0.210	-0	-0	-.000	-0	-0	-.000	-0	-0	-0
A056-10	7	102	0.200	83	92	0.180	88	36	0.090	-0	70050	100009
A058-06	7	92	0.200	76	86	0.177	82	37	0.090	-0	60255	-0
A061-06	7	132	0.150	57	70	0.111	90	37	0.070	-0	65040	100000
A056-02	7	99	0.100	48	59	0.082	60	28	0.060	-0	67280	100230

* MAXIMUM STRAIN WAS NOT ACHIEVED IN THE FIRST CYCLE.

SPECIMEN DESIGN:

SPECIMEN ID	MACH	E AT TEST TEMP. GPa	STRN RNG%	1st CYCLE STSS RNG MPa	1st CYCLE MAX STSS MPa	1st CYCLE MAX STRN %	Ni/2 (Nf/2 if no Ni) STSS RNG MPa	Ni/2 (Nf/2 if no Ni) MAX STSS MPa	Ni/2 (Nf/2 if no Ni) ELAST STRN %	Ni CYCLES	N5 CYCLES	Nf CYCLES

ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

A057-04 CRACK DESC.: OG;S;-0.30;MULTIPLE INITIATIONS;---;---;P
COMMENTS: TRANSVERSE. RT E = 120 GPa. STRAIN RANGE ATTAINED IN 14 CYCLES. ONE HALF OF SPECIMEN WAS BROKEN (NOW IN THREE PIECES) WHILE UNLOADING FROM MACHINE AFTER FAILURE.

A082-03 CRACK DESC.: UNLOADED IN ONE PIECE
COMMENTS: TRANSVERSE. RT E = 122 GPa. STRAIN RANGE ATTAINED ON 1st CYCLE. STOPPED TEST - RUNOUT AT 100,000 CYCLES.

A057-08 CRACK DESC.: OG;S;-0.45;MULTIPLE INITIATIONS;---;---;P
COMMENTS: TRANSVERSE. RT E = 137 GPa. STRAIN RANGE ATTAINED IN 7 CYCLES.

A056-06 CRACK DESC.: OG;S;-0.40;MULTIPLE INITIATIONS;---;---;P
COMMENTS: TRANSVERSE. RT E = 126 GPa. STRAIN ATTAINED IN 10 CYCLES.

A057-02 CRACK DESC.: OG;S;+0.30;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: TRANSVERSE. RT E = 134 GPa. STRAIN RANGE ATTAINED IN 24 CYCLES.

A056-08 CRACK DESC.: OG;I&S;+0.30;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: TRANSVERSE. RT E = 155 GPa. STRAIN RANGE ATTAINED IN 14 CYCLES.

A082-10 CRACK DESC.: UNLOADED IN ONE PIECE
COMMENTS: TRANSVERSE. RT E = 150 GPa. STRAIN RANGE ATTAINED IN 7 CYCLES. STOPPED TEST - RUNOUT AT 100,000 CYCLES. SPECIMEN WAS OBSERVED TO BE BENT AFTER TESTING.

A056-04 CRACK DESC.: SPECIMEN BROKEN DURING LOADING
COMMENTS: TRANSVERSE. VOID TEST.

A056-10 CRACK DESC.: UNLOADED IN ONE PIECE
COMMENTS: TRANSVERSE. RT E = 123 GPa. STRAIN RANGE ATTAINED IN 10 CYCLES. STOPPED TEST - RUNOUT AT 100,009 CYCLES.

A058-06 CRACK DESC.: SEE COMMENTS
COMMENTS: TRANSVERSE. RT E = 115 GPa. STRAIN RANGE ATTAINED IN 6 CYCLES. AT CYCLE 76913 POWER OUTAGE SHUT TEST DOWN CAUSING WEIGHT OF PLATEN TO BE APPLIED TO SPECIMEN, PULLING IT IN TWO PIECES. DATA VALID UP TO THIS POINT

A061-06	CRACK DESC.:	UNLOADED IN ONE PIECE
	COMMENTS:	TRANSVERSE. RT E = 152 GPa. STRAIN RANGE ATTAINED IN 9 CYCLES. STOPPED TEST - RUNOUT AT 100,000 CYCLES.
A056-02	CRACK DESC.:	UNLOADED IN ONE PIECE.
	COMMENTS:	TRANSVERSE. RT E = 130 GPa. STRAIN RANGE ATTAINED IN 8 CYCLES. STOPPED TEST - RUNOUT AT 100,230 CYCLES.

Material's Behavior Research Corporation
TABLE II: STRESS-STRAIN DATA FOR FIRST LOAD-UP

TEMPERATURE: 649 DEG.C. R-RATIO: .1

PT.	SPECIMEN A057-04 E @START= 92 GPa STRESS MPa	STRAIN %	SPECIMEN A082-03 E @START= 92 GPa STRESS MPa	STRAIN %	SPECIMEN A057-08 E @START=109 GPa STRESS MPa	STRAIN %	SPECIMEN A056-06 E @START=101 GPa STRESS MPa	STRAIN %
1	26	0.030	50	0.060	32	0.030	14	0.010
2	44	0.050	61	0.090	48	0.050	27	0.025
3	56	0.070	67	0.110	60	0.080	40	0.040
4	63	0.090	77	0.140	71	0.110	52	0.055
5	70	0.110	82	0.160	78	0.130	60	0.070
6	75	0.130	90	0.190	85	0.150	66	0.085
7	82	0.150	96	0.210	91	0.170	71	0.100
8	89	0.170	105	0.240	98	0.190	76	0.115
9	97	0.190	112	0.260	104	0.210	80	0.130
10	101	0.210	120	0.296	112	0.235	86	0.146

PT.	SPECIMEN A057-02 E @START=105 GPa STRESS MPa	STRAIN %	SPECIMEN A056-08 E @START=133 GPa STRESS MPa	STRAIN %	SPECIMEN A082-10 E @START=124 GPa STRESS MPa	STRAIN %	SPECIMEN A056-04 E @START= N/A STRESS MPa	STRAIN %
1	11	0.010	18	0.010	26	0.020	-0	-0.000
2	27	0.030	27	0.020	41	0.040	-0	-0.000
3	41	0.050	36	0.030	51	0.060	-0	-0.000
4	50	0.070	49	0.050	58	0.080	-0	-0.000
5	57	0.090	55	0.060	65	0.100	-0	-0.000
6	65	0.110	62	0.080	71	0.120	-0	-0.000
7	72	0.130	66	0.090	78	0.140	-0	-0.000
8	79	0.150	73	0.110	84	0.160	-0	-0.000
9	86	0.170	77	0.120	91	0.180	-0	-0.000
10	91	0.184	84	0.141	99	0.206	-0	-0.000

PT.	SPECIMEN A056-10 E @START=102 GPa STRESS MPa	STRAIN %	SPECIMEN A058-06 E @START= 92 GPa STRESS MPa	STRAIN %	SPECIMEN A061-06 E @START=132 GPa STRESS MPa	STRAIN %	SPECIMEN A056-02 E @START= 99 GPa STRESS MPa	STRAIN %
1	9	0.010	33	0.040	15	0.010	12	0.010
2	24	0.025	40	0.050	24	0.020	20	0.020
3	36	0.040	47	0.070	31	0.030	28	0.030
4	53	0.070	51	0.080	37	0.040	36	0.040
5	61	0.090	58	0.100	44	0.050	43	0.050
6	68	0.110	63	0.110	48	0.060	47	0.060
7	74	0.130	69	0.130	53	0.070	50	0.065
8	83	0.150	73	0.140	57	0.080	54	0.070
9	86	0.160	80	0.160	66	0.100	56	0.075
10	92	0.180	86	0.177	70	0.111	59	0.082

Material's Behavior Research Corporation

TABLE II

BOLTHOLE SPECIMEN FINAL DATA SUMMARY: 05-22-89

LCF LOAD CONTROLLED TESTS

STRESS R-RATIO: .1
TEMPERATURE, DEG.C.: 26
WAVEFORM: TRIANGULAR
FREQUENCY, Hz: .33
Kt: 2.5, LONGITUDINAL

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090C
P.O. No.: H838840

SPECIMEN I.D.	MACH. NO.	STRESS RANGE MPa	Nf CYCLES	CRACK DESCRIPTION
A097-02	3	992	-0	AT BOLTHOLE
A099-04	4	810	24	AT BOLTHOLE
A105-03	3	738	41	AT BOLTHOLE
A101-03	3	720	4038	AT BOLTHOLE
A101-02	3	675	42524	AT BOLTHOLE
A103-04	3	630	100048	UNLOADED IN ONE PIECE

NOTE: ABOVE, A '-0' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'

A097-02 COMMENTS: LONGITUDINAL. SPECIMEN FAILED ON INITIAL RAMP-UP AT 992 MPa BEFORE REACHING AIM OF 1200 MPa.
A099-04 COMMENTS: LONGITUDINAL. SPECIMEN POPPED OUT ON START-UP.
A105-03 COMMENTS: LONGITUDINAL.
A101-03 COMMENTS: LONGITUDINAL.
A101-02 COMMENTS: LONGITUDINAL.
A103-04 COMMENTS: LONGITUDINAL. STOPPED TEST - RUNOUT AT 100,048 CYCLES.

Material's Behavior Research Corporation

TABLE II

BOLTHOLE SPECIMEN FINAL DATA SUMMARY: 05-22-89

LCF LOAD CONTROLLED TESTS

Ti3AL/SCS-6 ALLOY

STRESS R-RATIO: .1
TEMPERATURE, DEG.C.: 26
WAVEFORM: TRIANGULAR
FREQUENCY, Hz: .33
Kt: 2.5, TRANSVERSE

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090C
P.O. No.: H838840

SPECIMEN I.D.	MACH. NO.	STRESS RANGE MPa	Nf CYCLES	CRACK DESCRIPTION
A062-03	8	155	8910	AT BOLTHOLE
A055-01	8	137	27995	AT BOLTHOLE
A062-01	8	124	60894	AT BOLTHOLE
A058-03	13	118	95300	AT BOLTHOLE
A061-03	8	111	100079	UNLOADED IN ONE PIECE.

NOTE: ABOVE, A '-0' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'

A062-03 COMMENTS: TRANSVERSE.
A055-01 COMMENTS: TRANSVERSE.
A062-01 COMMENTS: TRANSVERSE.
A058-03 COMMENTS: TRANSVERSE. UNABLE TO FIT EXTENSOMETERS ON SPECIMEN AFTER TWO FAILURES IN GRIPPING REGION, THEREFORE Ni'S ARE NOT AVAILABLE.
A061-03 COMMENTS: TRANSVERSE. STOPPED TEST - RUNOUT AT 100,079 CYCLES.

Material's Behavior Research Corporation

TABLE II

BOLTHOLE SPECIMEN FINAL DATA SUMMARY: 05-22-89

LCF LOAD CONTROLLED TESTS

Ti3AL/SCS-6 ALLOY

STRESS R-RATIO: .1
TEMPERATURE, DEG.C.: 649
WAVEFORM: TRIANGULAR
FREQUENCY, Hz: .33
Kt: 2.5, LONGITUDINAL

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090C
P.O. No.: H838840

SPECIMEN I.D.	MACH. NO.	STRESS RANGE MPa	Nf CYCLES	CRACK DESCRIPTION
A097-04	3	628	4831	AT BOLTHOLE
A099-02	3	540	5947	AT BOLTHOLE
A100-04	3	445	25794	AT BOLTHOLE
A102-03	3	401	69192	AT BOLTHOLE
A104-04	3	360	102839	UNLOADED IN ONE PIECE

NOTE: ABOVE, A '-0' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'

A097-04 COMMENTS: LONGITUDINAL.
A099-02 COMMENTS: LONGITUDINAL.
A100-04 COMMENTS: LONGITUDINAL.
A102-03 COMMENTS: LONGITUDINAL.
A104-04 COMMENTS: LONGITUDINAL. STOPPED TEST - RUNOUT AT 102,839 CYCLES.

Material's Behavior Research Corporation

TABLE II

BOLTHOLE SPECIMEN FINAL DATA SUMMARY: 05-22-89

LCF LOAD CONTROLLED TESTS

STRESS R-RATIO: .1
TEMPERATURE, DEG.C.: 649
WAVEFORM: TRIANGULAR
FREQUENCY, Hz: .33
Kt: 2.5, TRANSVERSE

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090C
P.O. No.: H838840

SPECIMEN I.D.	MACH. NO.	STRESS RANGE MPa	Nf CYCLES	CRACK DESCRIPTION
A058-04	8	124	69	AT BOLTHOLE
A058-01	8	93	313	AT BOLTHOLE
A055-05	14	74	18428	AT BOLTHOLE
A061-05	14	62	44905	AT BOLTHOLE
A055-03	8	31	100971	BROKEN UNLOADING AFTER RUNOUT

A058-04 COMMENTS: TRANSVERSE.
A058-01 COMMENTS: TRANSVERSE.
A055-05 COMMENTS: TRANSVERSE.
A061-05 COMMENTS: TRANSVERSE.
A055-03 COMMENTS: TRANSVERSE. STOPPED TEST - RUNOUT AT 100,971 CYCLES.

Material's Behavior Research Corporation
TABLE I

LCF SPECIMEN FINAL DATA SUMMARY: 04-17-89

AXIAL STRAIN MEASUREMENT AND CONTROL

Ti3AL/SCS-6

ALPHA, X 10^-6/DEG.C: 0
STRAIN R-RATIO: .5
TEMPERATURE, DEG.C: 26
WAVEFORM: TRIANGULAR
FREQUENCY Hz: .33
SPECIMEN DESIGN: LONGITUDINAL

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090A
P.O. No.: H838840

				1st CYCLE*			Ni/2 (Nf/2 if no Ni)					
SPECIMEN ID	MACH	E AT TEST TEMP. GPa	STRN RNG%	STSS RNG MPa	MAX STSS MPa	MAX STRN %	STSS RNG MPa	MAX STSS MPa	ELAST STRN %	Ni CYCLES	N5 CYCLES	Nf CYCLES
A100-05	6	190	0.380	550	684	0.960	594	477	0.310	-0	-0	100212
A051-01	1	191	0.350	608	1060	0.670	655	1025	0.340	38783	-0	38783
A074-10	4	180	0.330	545	935	0.620	537	475	0.300	-0	-0	100003
A051-02	11	194	0.320	548	974	0.580	633	955	0.330	7960	-0	8008
A074-08	14	187	0.310	502	854	0.555	511	740	0.280	-0	61155	103220
A074-04	10	189	0.300	478	850	0.527	521	761	0.280	-0	-0	100000

* MAXIMUM STRAIN WAS NOT ACHIEVED IN THE FIRST CYCLE.

ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

A100-05 CRACK DESC.: UNLOADED IN ONE PIECE
COMMENTS: LONGITUDINAL. STRAIN POPPED OUT TO 0.96% ON FIRST CYCLE. STRAIN RANGE ESTABLISHED AT CYCLE 50. STOPPED TEST - RUNOUT AT 100,212 CYCLES.

A051-01 CRACK DESC.: OG;S;-0.55;MULTIPLE INITIATIONS;---;---;P
COMMENTS: LONGITUDINAL. STRAIN RANGE ATTAINED IN 4 CYCLES.

A074-10 CRACK DESC.: UNLOADED IN ONE PIECE
COMMENTS: LONGITUDINAL. STRAIN POPPED OUT FROM 0.54% TO 0.73% AT CYCLE 2 & FROM 0.525% TO 0.765% AT CYCLE 3. STRAIN RANGE ESTABLISHED AT ~60 CYCLES. STOPPED TEST - RUNOUT AT 100,003 CYCLES.

A051-02 CRACK DESC.: OG;S;+0.55;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: LONGITUDINAL. STRAIN RANGE ATTAINED IN 25 CYCLES.

A074-08	CRACK DESC.:	UNLOADED IN ONE PIECE
	COMMENTS:	LONGITUDINAL. STRAIN RANGE ATTAINED IN 25 CYCLES. STOPPED TEST - RUNOUT AT 103,220 CYCLES.
A074-04	CRACK DESC.:	UNLOADED IN ONE PIECE
	COMMENTS:	LONGITUDINAL. STRAIN RANGE ATTAINED IN 8 CYCLES. STOPPED TEST - RUNOUT AT 100,000 CYCLES.

Material's Behavior Research Corporation
TABLE II: STRESS-STRAIN DATA FOR FIRST LOAD-UP

TEMPERATURE: 26 DEG.C. R-RATIO: .5

PT.	SPECIMEN A100-05 E @START=190 GPa STRESS MPa	STRAIN %	SPECIMEN A051-01 E @START=191 GPa STRESS MPa	STRAIN %	SPECIMEN A074-10 E @START=180 GPa STRESS MPa	STRAIN %	SPECIMEN A051-02 E @START=194 GPa STRESS MPa	STRAIN %
1	103	0.060	156	0.080	120	0.070	95	0.050
2	177	0.100	290	0.150	242	0.140	189	0.100
3	251	0.140	407	0.210	354	0.200	307	0.160
4	326	0.180	543	0.280	466	0.260	429	0.220
5	402	0.220	657	0.340	574	0.320	553	0.280
6	478	0.260	756	0.410	668	0.380	667	0.340
7	555	0.300	833	0.470	737	0.440	759	0.400
8	640	0.350	912	0.540	806	0.500	837	0.460
9	683	0.400	983	0.600	872	0.560	911	0.520
10	684	0.520	1060	0.670	935	0.620	974	0.580

PT.	SPECIMEN A074-08 E @START=187 GPa STRESS MPa	STRAIN %	SPECIMEN A074-04 E @START=189 GPa STRESS MPa	STRAIN %
1	101	0.050	96	0.050
2	194	0.100	193	0.100
3	284	0.150	286	0.150
4	378	0.200	384	0.200
5	470	0.250	475	0.250
6	554	0.300	564	0.300
7	631	0.350	644	0.350
8	693	0.400	710	0.400
9	752	0.450	767	0.450
10	854	0.555	850	0.527

Material's Behavior Research Corporation

TABLE II

BOLTHOLE SPECIMEN FINAL DATA SUMMARY: 05-22-89

LCF LOAD CONTROLLED TESTS

STRESS R-RATIO: .5
TEMPERATURE, DEG.C.: 26
WAVEFORM: TRIANGULAR
FREQUENCY, Hz: .33
Kt: 2.5, LONGITUDINAL

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090C
P.O. No.: H838840

SPECIMEN I.D.	MACH. NO.	STRESS RANGE MPa	Nf CYCLES	CRACK DESCRIPTION
A102-02	3	438	3581	AT BOLTHOLE
A104-03	3	438	697	AT BOLTHOLE
A100-02	3	425	40087	AT BOLTHOLE
A097-03	3	399	100045	UNLOADED IN ONE PIECE
A099-03	3	415	-0	AT BOLTHOLE

NOTE: ABOVE, A '-0' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'

A102-02 COMMENTS: LONGITUDINAL.
A104-03 COMMENTS: LONGITUDINAL.
A100-02 COMMENTS: LONGITUDINAL.
A097-03 COMMENTS: LONGITUDINAL. STOPPED TEST - RUNOUT AT 100,045 CYCLES.
A099-03 COMMENTS: LONGITUDINAL. SPECIMEN "POPPED" TWICE DURING START-UP, THEN FAILED AT 865 MPa WHILE ATTEMPTING TO OBTAIN 900 MPa.

Material's Behavior Research Corporation

TABLE I

LCF SPECIMEN FINAL DATA SUMMARY: 04-17-89

AXIAL STRAIN MEASUREMENT AND CONTROL

Ti_3AL/SCS-6

ALPHA, X 10^-6/DEG.C: 12.3
STRAIN R-RATIO: .5
TEMPERATURE, DEG.C: 649
WAVEFORM: TRIANGULAR
FREQUENCY Hz: .33
SPECIMEN DESIGN: LONGITUDINAL

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090A
P.O. No.: H838840

SPECIMEN ID	MACH	E AT TEST TEMP. GPa	STRN RNG%	1st CYCLE* STSS RNG MPa	1st CYCLE* MAX STSS MPa	1st CYCLE* MAX STRN %	Ni/2 (Nf/2 if no Ni) STSS RNG MPa	Ni/2 (Nf/2 if no Ni) MAX STSS MPa	Ni/2 (Nf/2 if no Ni) ELAST STRN %	Ni CYCLES	N5 CYCLES	Nf CYCLES
A104-05	4	163	0.380	622	1063	0.730	639	994	0.390	1828	-0	1828
A052-03	2	170	0.350	692	831	0.490	607	960	0.360	3250	3250	3298
A071-06	11	155	0.300	434	789	0.534	495	737	0.320	18080	19270	24680
A052-01	5	181	0.280	412	804	0.465	509	777	0.280	11976	-0	11976
A052-09	5	169	0.250	166	326	0.190	409	620	0.240	-0	0	100500
A071-08	11	-0	-.000	-0	-0	-.000	-0	-0	-.000	-0	-0	-0

* MAXIMUM STRAIN WAS NOT ACHIEVED IN THE FIRST CYCLE.

ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

A104-05 CRACK DESC.: IG;S;+0.08;---;0.00;0.11;P+S
COMMENTS: LONGITUDINAL. RT E = 188 GPa. STRAIN RANGE ATTAINED AT 5 CYCLES.

A052-03 CRACK DESC.: OG;S;+0.35;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: LONGITUDINAL. TEST SHUT DOWN ON FIRST CYCLE - SEE START-UP ON X-Y. RT E = 196 GPa. STRAIN RANGE ATTAINED IN 17 CYCLES.

A071-06 CRACK DESC.: IG;I&S;MULTIPLE INITIATIONS ON MULTIPLE PLANES;---;---
COMMENTS: LONGITUDINAL. RT E = 179 GPa. STRAIN RANGE ATTAINED IN 12 CYCLES.

A052-01 CRACK DESC.: IG;I&S;+0.24;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: LONGITUDINAL. RT E = 204 GPa. STRAIN RANGE ATTAINED IN 32 CYCLES.

A052-09	CRACK DESC.:	UNLOADED IN ONE PIECE.
	COMMENTS:	LONGITUDINAL. RT E = 192 GPa. STRAIN RANGE ATTAINED IN 28 CYCLES. STOPPED TEST - RUNOUT AT 100,300 CYCLES.
A071-08	CRACK DESC.:	SEE COMMENTS
	COMMENTS:	LONGITUDINAL. TEST INADVERTENTLY RUN AT INCORRECT R-RATIO. VOID TEST.

Material's Behavior Research Corporation

TABLE II: STRESS-STRAIN DATA FOR FIRST LOAD-UP

TEMPERATURE: 649 DEG.C. R-RATIO: .5

PT.	SPECIMEN A104-05 E @START=163 GPa STRESS MPa	STRAIN %	SPECIMEN A052-03 E @START=170 GPa STRESS MPa	STRAIN %	SPECIMEN A071-06 E @START=155 GPa STRESS MPa	STRAIN %	SPECIMEN A052-01 E @START=181 GPa STRESS MPa	STRAIN %
1	113	0.070	75	0.050	70	0.050	78	0.040
2	226	0.140	158	0.100	145	0.100	166	0.090
3	341	0.210	242	0.150	220	0.150	240	0.130
4	458	0.280	324	0.200	296	0.200	327	0.180
5	567	0.350	413	0.250	373	0.250	398	0.220
6	679	0.420	501	0.300	453	0.300	491	0.270
7	783	0.490	586	0.350	525	0.350	557	0.310
8	874	0.560	673	0.400	604	0.400	645	0.360
9	960	0.630	762	0.450	674	0.450	708	0.400
10	1063	0.730	831	0.490	789	0.534	804	0.465

PT.	SPECIMEN A052-09 E @START=169 GPa STRESS MPa	STRAIN %	SPECIMEN A071-08 E @START= N/A STRESS MPa	STRAIN %
1	35	0.020	-0	-0.000
2	71	0.040	-0	-0.000
3	101	0.060	-0	-0.000
4	135	0.080	-0	-0.000
5	170	0.100	-0	-0.000
6	206	0.120	-0	-0.000
7	241	0.140	-0	-0.000
8	269	0.160	-0	-0.000
9	305	0.180	-0	-0.000
10	326	0.190	-0	-0.000

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TABLE II

BOLTHOLE SPECIMEN FINAL DATA SUMMARY: 05-22-89

LCF LOAD CONTROLLED TESTS

STRESS R-RATIO: .5
TEMPERATURE, DEG.C.: 649
WAVEFORM: TRIANGULAR
FREQUENCY, Hz: .33
Kt: 2.5, LONGITUDINAL

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090C
P.O. No.: H838840

SPECIMEN I.D.	MACH. NO.	STRESS RANGE MPa	Nf CYCLES	CRACK DESCRIPTION
A098-02	3	349	3319	AT BOLTHOLE
A100-03	3	324	9966	AT BOLTHOLE
A101-04	3	299	20556	AT BOLTHOLE
A103-03	3	274	30449	AT BOLTHOLE
A105-02	3	248	103508	AT BOLTHOLE

NOTE: ABOVE, A '-0' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'

A098-02 COMMENTS: LONGITUDINAL.
A100-03 COMMENTS: LONGITUDINAL.
A101-04 COMMENTS: LONGITUDINAL.
A103-03 COMMENTS: LONGITUDINAL.
A105-02 COMMENTS: LONGITUDINAL.

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TABLE III

HCF SPECIMEN FINAL DATA SUMMARY: 03-20-89

LOAD CONTROLLED TESTS

STRESS R-RATIO: .1
TEMPERATURE, DEG.C.: 649
WAVEFORM: SINE
FREQUENCY, Hz: 30
Kt: 1 , LONGITUDINAL

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090B
P.O. No.: H838840

SPECIMEN I.D.	MACH. NO.	STRESS RANGE MPa	Nf CYCLES	CRACK DESCRIPTION
A53-02	12	631	93590	IN UNIFORM SECTION;S;MULTIPLE INITIATIONS
A53-08	12	540	504780	IN UNIFORM SECTION;S;MULTIPLE INITIATIONS
A54-06	12	449	2400100	IN UNIFORM SECTION;S;MULTIPLE INITIATIONS
A60-04	12	427	10000000	UNLOADED IN ONE PIECE
A59-06	12	405	10156000	UNLOADED IN ONE PIECE.

NOTE: ABOVE, A '-0' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'

A53-02 COMMENTS: LONGITUDINAL.
A53-08 COMMENTS: LONGITUDINAL.
A54-06 COMMENTS: LONGITUDINAL. HEATING COIL ARCED AGAINST SPECIMEN IN SHANK REGION WHEN SPECIMEN SLIPPED FROM GRIPS AT CYCLE 1,606,350. RELOADED AND CONTINUED TEST.
A60-04 COMMENTS: LONGITUDINAL. STOPPED TEST - RUNOUT AT 10,000,000 CYCLES.
A59-06 COMMENTS: LONGITUDINAL. STOPPED TEST - RUNOUT AT 10,156,000 CYCLES.

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TABLE III

HCF SPECIMEN FINAL DATA SUMMARY: 03-20-89

LOAD CONTROLLED TESTS

STRESS R-RATIO: .1
TEMPERATURE, DEG.C.: 649
WAVEFORM: SINE
FREQUENCY, Hz: 30
Kt: 1, TRANSVERSE

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090B
P.O. No.: H838840

SPECIMEN I.D.	MACH. NO.	STRESS RANGE MPa	Nf CYCLES	CRACK DESCRIPTION
A56-01	12	87	12022	IN UNIFORM SECTION;S;MULTIPLE INITIATIONS
A57-07	8	75	381942	IN UNIFORM SECTION;S;MULTIPLE INITIATIONS
A56-09	12	62	5178933	IN UNIFORM SECTION;S;MULTIPLE INITIATIONS
A55-06	11	56	10000913	UNLOADED IN ONE PIECE
A57-10	12	50	10010446	UNLOADED IN ONE PIECE

A56-01 COMMENTS: TRANSVERSE.
A57-07 COMMENTS: TRANSVERSE.
A56-09 COMMENTS: TRANSVERSE.
A55-06 COMMENTS: TRANSVERSE. STOPPED TEST - RUNOUT AT 10,000,913 CYCLES.
A57-10 COMMENTS: TRANSVERSE. STOPPED TEST - RUNOUT AT 10,010,446 CYCLES.

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TABLE III

BOLTHOLE SPECIMEN FINAL DATA SUMMARY: 05-22-89

LOAD CONTROLLED TESTS

STRESS R-RATIO: .1
TEMPERATURE, DEG.C.: 649
WAVEFORM: SINE
FREQUENCY, Hz: 30
Kt: 2.5, LONGITUDINAL

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090B
P.O. No.: H838840

SPECIMEN I.D.	MACH. NO.	STRESS RANGE MPa	Nf CYCLES	CRACK DESCRIPTION
A103-02	12	405	368266	CRACKING ON BOTH SIDES OF BOLTHOLE
A098-04	12	360	424801	CRACKING ON BOTH SIDES OF BOLTHOLE
A104-02	13	315	1252318	CRACKING ON BOTH SIDES OF BOLTHOLE
A105-04	8	293	738799	CRACKING ON BOTH SIDES OF BOLTHOLE
A102-04	12	270	10366560	UNLOADED IN ONE PIECE

A103-02 COMMENTS: LONGITUDINAL.
A098-04 COMMENTS: LONGITUDINAL.
A104-02 COMMENTS: LONGITUDINAL.
A105-04 COMMENTS: LONGITUDINAL.
A102-04 COMMENTS: LONGITUDINAL. STOPPED TEST - RUNOUT AT 10,366,560 CYCLES.

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TABLE III

HCF SPECIMEN FINAL DATA SUMMARY: 03-20-89

LOAD CONTROLLED TESTS

STRESS R-RATIO: .5
TEMPERATURE, DEG.C.: 649
WAVEFORM: SINE
FREQUENCY, Hz: 30
Kt: 1, LONGITUDINAL

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090B
P.O. No.: H838840

SPECIMEN I.D.	MACH. NO.	STRESS RANGE MPa	Nf CYCLES	CRACK DESCRIPTION
A60-05	8	399	304087	IN UNIFORM SECTION;S;MULTIPLE INITIATIONS
A60-06	12	375	1014156	IN UNIFORM SECTION;S;MULTIPLE INITIATIONS
A54-07	12	369	474928	IN UNIFORM SECTION;S;MULTIPLE INITIATIONS
A59-05	8	350	10000695	UNLOADED IN ONE PIECE
A53-01	12	301	10515500	UNLOADED IN ONE PIECE

NOTE: ABOVE, A '-0' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'

A60-05 COMMENTS: LONGITUDINAL.
A60-06 COMMENTS: LONGITUDINAL. HEATING COIL ARCED AGAINST ONE HALF OF SPECIMEN AFTER FAILURE.
A54-07 COMMENTS: LONGITUDINAL.
A59-05 COMMENTS: LONGITUDINAL. STOPPED TEST - RUNOUT AT 10,000,695 CYCLES.
A53-01 COMMENTS: LONGITUDINAL. STOPPED TEST - RUNOUT AT 10,515,500.

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TABLE III

HCF SPECIMEN FINAL DATA SUMMARY: 03-20-89

LOAD CONTROLLED TESTS

STRESS R-RATIO: .1
TEMPERATURE, DEG.C.: 26
WAVEFORM: SINE
FREQUENCY, Hz: 30
Kt: 1 , LONGITUDINAL

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-090B
P.O. No.: H838840

SPECIMEN I.D.	MACH. NO.	STRESS RANGE MPa	Nf CYCLES	CRACK DESCRIPTION
A59-02	7	704	488670	IN UNIFORM SECTION;S;MULTIPLE INITIATIONS
A54-10	12	661	2161400	IG;S & SS;MULTIPLE INITIATIONS
A53-04	10	639	473880	IN UNIFORM SECTION;S;MULTIPLE INITIATIONS
A60-03	10	611	4688410	NEAR R.U.S.I.;S;MULTIPLE INITIATIONS
A59-03	10	586	4227240	IN UNIFORM SECTION;S;MULTIPLE INITIATIONS

NOTE: ABOVE, A '-0' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'

A59-02 COMMENTS: LONGITUDINAL.
A54-10 COMMENTS: LONGITUDINAL.
A53-04 COMMENTS: LONGITUDINAL.
A60-03 COMMENTS: LONGITUDINAL.
A59-03 COMMENTS: LONGITUDINAL.

TASK VI LCF & HCF DATA

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TABLE I

LCF SMOOTH SPECIMEN FINAL DATA SUMMARY 06-18-88

AXIAL STRAIN MEASUREMENT AND CONTROL

BIC/TI3AL ALLOY

ALPHA X 10^-6 /DEG F. 6 8
STRAIN R-RATIO 1
TEMPERATURE DEG F 1400
WAVEFORM TRIANGULAR
FREQUENCY Hz 33
SPECIMEN DESIGN.

ACT Engineer GAMBONE
Vendor phone (513)-248-1722
MBRC Job No. 810-880
P O No. H803427

SPECIMEN ID	MACH	R.T. DIAM. IN	HOT AREA SQ IN	EOTEST TEMP X10^6 PSI START	EOTEST TEMP X10^6 PSI NI/2	STRN RNG%	FIRST CYCLE* STSS RNG KSI	FIRST CYCLE* MAX STSS KSI	FIRST CYCLE* MAX STRN %	AT NI/2 STSS RNG KSI	AT NI/2 MAX STSS KSI	AT NI/2 MIN STSS KSI	AT NI/2 STRN COMPONENTS ELAST	AT NI/2 STRN COMPONENTS PLASTIC CALC	AT NI/2 STRN COMPONENTS PLASTIC MEAS	AT NI/2 STSS RNG KSI	AT NI/2 MAX STSS KSI	AT NI/2 MIN STSS KSI	AT NI/2 STRN COMPONENTS ELAST	AT NI/2 STRN COMPONENTS PLASTIC CALC	AT NI/2 STRN COMPONENTS PLASTIC MEAS	CYCLIC LIFE NI CYCLES	CYCLIC LIFE N5 CYCLES	CYCLIC LIFE NF CYCLES

****NOTE. BELOW, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE' ****

SPECIMEN ID	MACH	R.T. DIAM. IN	HOT AREA SQ IN	START	NI/2	STRN RNG%	STSS RNG KSI	MAX STSS KSI	MAX STRN %	STSS RNG KSI	MAX STSS KSI	MIN STSS KSI	ELAST	PLASTIC CALC	PLASTIC MEAS	STSS RNG KSI	MAX STSS KSI	MIN STSS KSI	ELAST	PLASTIC CALC	PLASTIC MEAS	NI CYCLES	N5 CYCLES	NF CYCLES
27L-05	5	-.0000	.0224	21.8	-0.0	0.700	155.1	155.1	0.740	-0.0	-0.0	-0.0	-.000	-.000	-.000	-0.0	-0.0	-0.0	-.000	-.000	-.000	-0	-0	-0
27L-09	5	-.0000	.0222	24.7	24.7	0.600	131.1	139.6	0.630	136.9	132.1	-4.8	0.550	0.050	0.025	135.7	128.2	-7.5	0.550	0.050	0.025	740	1340	1377
16L-13	6	-.0000	.0231	21.6	21.6	0.500	75.3	95.2	0.440	102.8	103.8	1.0	0.480	0.020	0.020	102.8	103.4	0.6	0.480	0.020	0.020	1725	-0	1737
15L-07	6	-.0000	.0233	20.7	20.7	0.450	86.1	90.1	0.460	86.3	87.5	1.2	0.420	0.030	0.015	86.7	87.7	1.0	0.420	0.030	0.015	4220	4640	4672
15L-04	6	-.0000	.0238	21.7	21.7	0.420	69.1	[illegible]	0.410	84.5	85.7	1.2	0.390	0.030	0.015	84.0	86.5	2.5	0.390	0.030	0.015	3880	5260	6744
16L-18	6	-.0000	.0239	21.5	21.5	0.400	63.3	[illegible]	0.370	79.3	81.4	2.1	0.370	0.030	0.010	68.8	67.9	-0.9	0.320	0.080	0.020	3820	12120	22874
27L-01	5	-.0000	.0219	20.5	20.5	0.400	78.6	81.0	0.375	80.2	73.5	-6.7	0.390	0.010	0.020	76.4	69.3	-7.1	0.370	0.030	0.025	11800	9850	16360
15L-01	4	-.0000	.0233	20.6	20.6	0.380	67.3	76.3	0.360	70.2	59.8	-10.4	0.340	0.040	0.010	60.5	60.4	-8.1	0.330	0.050	0.015	32540	32540	47369
16L-07	4	-.0000	.0233	14.9	14.9	0.380	54.4	58.5	0.380	61.9	64.7	2.8	0.420	-.040	-.000	61.1	64.5	3.4	0.410	-.030	0.010	3420	-0	4829
16L-01	4	-.0000	.0240	23.7	23.7	0.350	60.4	68.1	0.320	63.9	49.6	-14.3	0.270	0.080	0.025	62.2	46.3	-15.9	0.240	0.090	0.025	1420	1710	2960
32-04	2	-.0000	.0220	14.0	14.0	0.495	56.1	57.3	0.430	67.1	58.4	-8.7	0.480	0.020	0.025	61.1	50.6	-10.5	0.440	0.060	0.025	1620	2600	3071
32-01	2	-.0000	.0217	16.9	16.9	0.400	57.6	54.1	0.380	57.9	48.7	-9.2	0.340	0.060	0.020	57.7	48.5	-9.2	0.340	0.060	0.020	4600	5140	5170
33-05	3	-.0000	.0226	14.6	14.6	0.400	49.8	52.5	0.390	55.2	47.0	-6.2	0.380	0.020	0.020	52.6	46.2	-6.4	0.360	0.040	0.020	5680	9316	9316
32-09	2	-.0000	.0217	15.9	15.9	0.350	46.9	49.5	0.350	49.9	38.5	-11.4	0.310	0.040	0.015	46.7	38.7	-8.0	0.290	0.060	0.015	21140	34680	40939

* MAXIMUM STRAIN WAS NOT ACHIEVED IN THE FIRST CYCLE.

SPECIMEN ID	MACH	RT DIAM IN	NOT AREA SQ IN	E@TEST TEMP x10^6 PSI START	E@TEST TEMP x10^6 PSI NI/2	STRN RNG %	FIRST CYCLE* STSS RNG KSI	FIRST CYCLE* MAX STSS KSI	FIRST CYCLE* MAX STRN %	AT NI/2 STSS RNG KSI	AT NI/2 MAX STSS KSI	AT NI/2 MIN STSS KSI	AT NI/2 STRN COMPONENTS ELAST	AT NI/2 STRN COMPONENTS PLASTIC CALC	AT NI/2 STRN COMPONENTS PLASTIC MEAS	AT NF/2 STSS RNG KSI	AT NF/2 MAX STSS KSI	AT NF/2 MIN STSS KSI	AT NF/2 STRN COMPONENTS ELAST	AT NF/2 STRN COMPONENTS PLASTIC CALC	AT NF/2 STRN COMPONENTS PLASTIC MEAS	CYCLIC LIFE NI CYCLES	CYCLIC LIFE N5 CYCLES	CYCLIC LIFE NF CYCLES
							****NOTE BELOW, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE' ****																	
33-09	3	-.0000	.0225	13.9	13.9	0.320	33.3	35.6	0.270	37.8	32.2	-5.6	0.270	0.050	0.015	35.8	29.7	-5.3	0.250	0.070	0.020	44810	44810	89372
45-04	7	-.0000	.0236	11.4	11.4	0.500	41.9	42.4	0.435	48.1	38.5	-9.6	0.420	0.080	0.035	47.0	37.6	-9.4	0.410	0.090	0.035	3020	4045	4064
45-10	7	-.0000	.0231	11.7	11.7	0.495	50.9	49.8	0.525	-0.0	-0.0	-0.0	-.000	-.000	-.000	-0.0	-0.0	-0.0	-.000	-.000	-.000	-0	-0	-0
35-09	13	-.0000	.0244	9.1	9.1	0.400	30.1	34.8	0.410	30.5	28.4	-2.1	0.340	0.060	0.030	28.1	25.8	-2.3	0.310	0.090	0.030	9300	11400	19364
45-07	7	-.0000	.0234	13.5	13.5	0.350	31.4	33.1	0.330	34.9	23.6	-11.3	0.260	0.090	0.030	34.1	23.4	-10.7	0.250	0.100	0.030	14780	-0	19995
35-02	14	-.0000	.0245	9.2	9.2	0.320	18.7	19.9	0.220	26.9	22.2	-4.7	0.290	0.030	0.020	26.3	20.8	-5.5	0.290	0.030	0.040	6520	-0	10431

27L-05 CRACK DESCRIPTION. FAILED ON RAMP-UP AT 0.74%, 155.134ksi.
COMMENTS. LONGITUDINAL. RT WIDTH = 0.2970"; RT THICKNESS = 0.0740". SPECIMEN WAS WARPED UPON RECEIPT
27L-09 CRACK DESCRIPTION. OG,S,-0.40,MULTIPLE INITIATIONS
COMMENTS LONGITUDINAL. RT WIDTH = 0.2990", RT THICKNESS = 0.0730". ADDITIONAL CRACKING ALONG UNIFORM SECTION.
16L-13 CRACK DESCRIPTION IG,S,-0.24,MULTIPLE INITIATIONS
COMMENTS LONGITUDINAL. RT WIDTH = 0.2960", RT THICKNESS = 0.0765".
15L-07 CRACK DESCRIPTION. OG,S,+0.53,MULTIPLE INITIATIONS
COMMENTS LONGITUDINAL. RT WIDTH = 0.3010"; RT THICKNESS = 0.0760".
15L-04 CRACK DESCRIPTION. OG,S,-0.30,MULTIPLE INITIATIONS
COMMENTS. LONGITUDINAL. RT WIDTH = 0.3000"; RT THICKNESS = 0.0780".
16L-10 CRACK DESCRIPTION OG,S,+0.27,MULTIPLE INITIATIONS
COMMENTS. LONGITUDINAL. RT WIDTH = 0.3010"; RT THICKNESS = 0.0780".
27L-01 CRACK DESCRIPTION. IG,S,+0.30,MULTIPLE INITIATIONS
COMMENTS. LONGITUDINAL. RT WIDTH = 0.2950", RT THICKNESS = 0.0730". SPECIMEN WAS WARPED UPON RECEIPT.
15L-01 CRACK DESCRIPTION. IG,S,MULTIPLE INITIATIONS ON MULTIPLE PLANES
COMMENTS. LONGITUDINAL. RT WIDTH = 0.2962", RT THICKNESS = 0.0773".
16L-07 CRACK DESCRIPTION. OG,S,-0.60,MULTIPLE INITIATIONS
COMMENTS LONGITUDINAL. RT WIDTH = 0.2967", RT THICKNESS = 0.0770". SPECIMEN WAS WARPED UPON RECEIPT.
16L-01 CRACK DESCRIPTION. OG,S,OR U S I ,MULTIPLE INITIATIONS
COMMENTS LONGITUDINAL. RT WIDTH = 0.3013", RT THICKNESS = 0.0781"
32-04 CRACK DESCRIPTION. IG,S,0.80,MULTIPLE INITIATIONS
COMMENTS 0 DEG /90 DEG CROSSPLY. RT WIDTH = 0.3025"; RT THICKNESS = 0.0715".
32-01 CRACK DESCRIPTION IG,S,MULTIPLE INITIATIONS
COMMENTS 0 DEG /90 DEG CROSSPLY. RT WIDTH = 0.3020", RT THICKNESS = 0.0704"
33-05 CRACK DESCRIPTION OG,S,-0.50,MULTIPLE INITIATIONS
COMMENTS 0 DEG /90 DEG CROSSPLY RT WIDTH = 0.3023", RT THICKNESS = 0.0735"
32-09 CRACK DESCRIPTION 2 PLANES OF FAILURE OG,S,+0.31 & +0.43,MULTIPLE INITIATIONS,---,---,P+S
COMMENTS 0 DEG /90 DEG CROSSPLY RT WIDTH = 0.3030", RT THICKNESS = 0.0704". Ni BASED ON CHANGE IN STRESS RANGE
33-01 CRACK DESCRIPTION IG,S,MULTIPLE INITIATIONS ON MULTIPLE PLANES
COMMENTS 0 DEG /90 DEG CROSSPLY. RT WIDTH = 0.3030", RT THICKNESS = 0.0730".
45-04 CRACK DESCRIPTION OG,S,-0.47,MULTIPLE INITIATIONS
COMMENTS 0 DEG /P/M 45 DEG /90 DEG. CROSSPLY. RT WIDTH = 0.3025", RT THICKNESS = 0.0765". ADDITIONAL CRACKING ALONG UNIFORM SECTION
SPECIMEN WAS WARPED UPON RECEIPT
45-10 CRACK DESCRIPTION SPECIMEN BUCKLED DUE TO EXTENSOMETER OSCILLATION AFTER 2 CYCLES
COMMENTS 0 DEG /P/M 45 DEG/90 DEG CROSSPLY. RT WIDTH = 0.3025", RT THICKNESS = 0.0750" VOID TEST SPECIMEN WAS WARPED UPON RECEIPT
35-09 CRACK DESCRIPTION IG,S,MULTIPLE INITIATIONS
COMMENTS 0 DEG /P/M 45 DEG /90 DEG. CROSSPLY RT WIDTH = 0.2960", RT THICKNESS = 0.0818"
45-07 CRACK DESCRIPTION OG,S,-0.35,MULTIPLE INITIATIONS
COMMENTS 0 DEG /P/M 45 DEG/90 DEG CROSSPLY RT WIDTH = 0.3025", RT THICKNESS = 0.0760" SPECIMEN WAS WARPED UPON RECEIPT
35-02 CRACK DESCRIPTION IG,S,-0.24,MULTIPLE INITIATIONS
COMMENTS 0 DEG /P/M 45 DEG /90 DEG CROSSPLY. RT WIDTH = 0.2955", RT THICKNESS = 0.0813" SPECIMEN WAS WARPED UPON RECEIPT

* MAXIMUM STRAIN WAS NOT ACHIEVED IN THE FIRST CYCLE.

Material's Behavior Research Corporation
TABLE III. STRESS-STRAIN DATA FOR FIRST LOAD-UP
Kt=1.0, STRAIN CONTROL

TEMPERATURE: 1400 DEG. F.
R-RATIO: .1

PT.	SPECIMEN 27L-05 EONi/2 -0 0x10^6 STRESS KSI	STRAIN %	SPECIMEN 27L-09 EONi/2. 24.7x10^6 STRESS KSI	STRAIN %	SPECIMEN 16L-13 EONi/2. 21.6x10^6 STRESS KSI	STRAIN %	SPECIMEN 15L-07 EONi/2. 20.7x10^6 STRESS KSI	STRAIN %	SPECIMEN 15L-04 EONi/2. 21.7x10^6 STRESS KSI	STRAIN %	SPECIMEN 16L-18 EONi/2. 21.5x10^6 STRESS KSI	STRAIN %	SPECIMEN 27L-01 EONi/2 20.5x10^6 STRESS KSI	STRAIN %	SPECIMEN 15L-01 EONi/2: 20.6x10^6 STRESS KSI	STRAIN %
1	9.375	0.050	29.640	0.120	11.260	0.050	10.350	0.050	8.680	0.040	8.600	0.040	7.991	0.040	4.290	0.020
2	20.313	0.100	44.460	0.180	22.080	0.100	20.700	0.100	17.360	0.080	17.200	0.080	16.553	0.080	8.580	0.040
3	43.304	0.200	58.559	0.240	33.330	0.150	31.330	0.150	25.310	0.120	25.520	0.120	25.114	0.120	16.740	0.080
4	45.179	0.300	73.872	0.300	43.720	0.200	41.630	0.200	33.610	0.160	33.470	0.160	33.676	0.160	25.110	0.120
5	87.500	0.400	85.586	0.360	54.550	0.250	51.500	0.250	42.020	0.200	40.590	0.200	42.808	0.200	34.010	0.160
6	109.375	0.500	98.874	0.420	64.940	0.300	60.300	0.300	51.470	0.240	48.120	0.240	51.484	0.240	42.920	0.200
7	129.464	0.600	111.486	0.480	74.680	0.350	70.390	0.350	56.930	0.280	55.230	0.280	60.502	0.280	53.430	0.240
8	138.839	0.650	123.649	0.540	84.420	0.400	79.480	0.400	64.710	0.320	60.470	0.310	69.064	0.320	60.690	0.280
9	147.545	0.700	135.135	0.600	90.260	0.430	84.760	0.430	71.850	0.360	66.100	0.340	75.571	0.350	68.450	0.320
10	155.134	0.740	139.640	0.630	95.230	0.460	90.129	0.460	81.720	0.410	71.879	0.370	81.049	0.375	76.290	0.360

PT.	SPECIMEN 16L-07 EONi/2. 14.9x10^6 STRESS KSI	STRAIN %	SPECIMEN 16L-01 EONi/2. 23.7x10^6 STRESS KSI	STRAIN %	SPECIMEN 32-04 EONi/2: 14.0x10^6 STRESS KSI	STRAIN %	SPECIMEN 32-01 EONi/2: 16.9x10^6 STRESS KSI	STRAIN %	SPECIMEN 33-05 EONi/2: 14.4x10^6 STRESS KSI	STRAIN %	SPECIMEN 32-09 EONi/2 15.9x10^6 STRESS KSI	STRAIN %	SPECIMEN 33-09 EONi/2 13.9x10^6 STRESS KSI	STRAIN %	SPECIMEN 45-04 EONi/2. 11.4x10^6 STRESS KSI	STRAIN %
1	4.510	0.040	9.480	0.040	11.200	0.080	6.760	0.040	5.840	0.040	7.950	0.050	4.170	0.030	9.120	0.080
2	10.420	0.080	18.960	0.080	16.800	0.120	13.134	0.080	11.680	0.080	14.055	0.090	8.340	0.060	13.242	0.120
3	16.090	0.120	26.870	0.110	22.400	0.160	19.470	0.120	17.520	0.120	19.816	0.130	12.510	0.090	17.797	0.160
4	21.570	0.160	33.180	0.140	27.841	0.200	25.230	0.160	23.360	0.160	25.461	0.170	16.542	0.120	22.034	0.200
5	28.110	0.200	39.580	0.170	33.068	0.240	30.874	0.200	28.762	0.200	29.724	0.200	20.230	0.150	25.847	0.240
6	34.550	0.240	45.830	0.200	38.636	0.280	35.829	0.240	34.072	0.240	33.525	0.230	24.454	0.180	29.555	0.280
7	40.990	0.280	52.190	0.230	43.864	0.320	41.244	0.280	39.382	0.280	37.673	0.260	28.122	0.210	32.945	0.320
8	48.280	0.320	58.440	0.260	49.205	0.360	46.198	0.320	44.249	0.320	41.590	0.290	30.678	0.230	35.464	0.360
9	54.720	0.360	64.380	0.290	54.545	0.400	51.152	0.360	49.559	0.360	45.307	0.320	33.346	0.250	39.301	0.400
10	58.497	0.380	68.092	0.320	57.273	0.430	54.149	0.380	52.543	0.390	49.539	0.350	35.556	0.270	42.374	0.435

	SPECIMEN 45-10		SPECIMEN 35-09		SPECIMEN 45-07		SPECIMEN 35-02	
	EON1/2. $11.7x10^6$		EON1/2. $9.1x10^6$		EON1/2. $13.5x10^6$		EON1/2. $9.2x10^6$	
	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN
PT	KSI	%	KSI	%	KSI	%	KSI	%
1	11.700	0.100	3.640	0.040	6.750	0.050	3.680	0.040
2	17.320	0.150	7.280	0.080	11.445	0.090	5.520	0.060
3	22.080	0.200	10.920	0.120	14.850	0.120	7.360	0.080
4	27.160	0.250	14.560	0.160	18.056	0.150	9.200	0.100
5	31.820	0.300	18.200	0.200	21.154	0.180	11.040	0.120
6	36.150	0.350	21.619	0.240	24.145	0.210	12.880	0.140
7	40.130	0.400	24.795	0.280	26.016	0.240	14.390	0.160
8	43.400	0.440	28.279	0.320	28.432	0.270	16.330	0.180
9	46.340	0.480	31.455	0.360	32.150	0.300	17.760	0.200
10	49.780	0.525	34.836	0.410	33.121	0.330	19.099	0.220

TABLE II

LCF SMOOTH SPECIMEN FINAL DATA SUMMARY 04-10-88

LOAD CONTOLLED TESTS

SiC/Ti3AL ALLOY

MBRC JOB 010-080
CUSTOMER ALLISON
P O H803427
RELEASE
CONTACT GAMBONE

SPEC I D	R-RATIO	MACH NO	Kt	ROOM TEMPERATURE DIMENSIONS DIAM IN	WIDTH IN	THICK IN	AREA SQ IN	TEST TEMP AREA SQ IN	TEST TEMP DEG F	FREQ HZ	THERMAL EXP COEFF X10^-6 IN/IN/DEG F	MAX LOAD LBS	MIN LOAD LBS	LOAD RANGE LBS	MAX STRESS KSI	MIN STRESS KSI	STRESS RANGE KSI	FINAL CYCLE	RUN TIME HOURS
6L-05	1	12	1.0		0.2970	0.0780	0.0232	0.0236	1400	30.0000	6.80	2124.0	212.4	1911.6	90.00	9.00	81.00	71930	0.67
6L-04	1	12	1.0		0.3010	0.0770	0.0232	0.0236	1400	30.0000	6.80	1888.0	188.8	1699.2	80.00	8.00	72.00	183520	1.70
16L-11	1	12	1.0		0.3010	0.0760	0.0229	0.0233	1400	30.0000	6.80	1631.0	163.1	1467.9	70.00	7.00	63.00	477650	4.42
16L-17	1	12	1.0		0.3010	0.0780	0.0235	0.0239	1400	30.0000	6.80	1434.0	143.4	1290.6	60.00	6.00	54.00	1127810	10.44
16L-10	1	16	1.0		0.3020	0.0770	0.0233	0.0237	1400	30.0000	6.80	1066.5	106.7	959.9	45.00	4.50	40.50	10021200	92.79
33-10	1	9	1.0		0.3030	0.0730	0.0221	0.0225	1400	30.0000	6.80	1462.5	146.3	1316.3	65.00	6.50	58.50	4940	0.05
33-03	1	10	1.0		0.3020	0.0740	0.0223	0.0228	1400	30.0000	6.80	912.0	91.2	820.8	40.00	4.00	36.00	1417650	13.13

****NOTE BELOW, A 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE' ****

16L-05 CRACK DESCRIPTION IN UNIFORM SECTION,S,MULTIPLE INITIATIONS,P+S WAVEFORM TRIANGULAR
16L-05 COMMENTS LONGITUDINAL

16L-04 CRACK DESCRIPTION IN UNIFORM SECTION,S,MULTIPLE INITIATIONS,P+S WAVEFORM TRIANGULAR
16L-04 COMMENTS LONGITUDINAL

16L-11 CRACK DESCRIPTION IN UNIFORM SECTION,S,P+S WAVEFORM TRIANGULAR
16L-11 COMMENTS LONGITUDINAL

16L-17 CRACK DESCRIPTION IN UNIFORM SECTION,I & S,MULTIPLE INITIATIONS WAVEFORM TRIANGULAR
16L-17 COMMENTS LONGITUDINAL

16L-10 CRACK DESCRIPTION UNLOADED IN ONE PIECE WAVEFORM TRIANGULAR
16L-10 COMMENTS LONGITUDINAL STOPPED TEST - RUNOUT AT 10021200 CYCLES

33-10 CRACK DESCRIPTION IN UNIFORM SECTION,S,MULTIPLE INITIATIONS,P+S WAVEFORM TRIANGULAR
33-10 COMMENTS 0 DEG /90 DEG CROSSPLY

33-03 CRACK DESCRIPTION IN UNIFORM SECTION,S,MULTIPLE INITIATIONS WAVEFORM TRIANGULAR
33-03 COMMENTS 0 DEG /90 DEG CROSSPLY

PAGE 2

SPEC I D	R-RATIO	MACH NO	Kt	ROOM TEMPERATURE DIMENSIONS DIAM IN	WIDTH IN	THICK IN	AREA SQ IN	TEST TEMP AREA SQ IN	TEST TEMP DEG F	FREQ HZ	THERMAL EXP COEFF X10^-6 IN/IN/DEG F	MAX LOAD LBS	MIN LOAD LBS	LOAD RANGE LBS	MAX STRESS KSI	MIN STRESS KSI	STRESS RANGE KSI	FINAL CYCLE	RUN TIME HOURS
****NOTE BELOW, A 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE' ****																			
32-05	1	10	1 0		0 3035	0 0720	0 0219	0 0222	1400	30 0000	6 80	777 0	77 7	699 3	35 00	3 50	31 50	3573130	33 08
32-05 CRACK DESCRIPTION	IN UNIFORM SECTION,S,MULTIPLE INITIATIONS,P+S WAVEFORM TRIANGULAR																		
32-05 COMMENTS	0 DEG /90 DEG CROSSPLY																		
33-04	1	9	1 0		0 3030	0 0740	0 0224	0 0228	1400	30 0000	6 80	684 0	68 4	615 6	30 00	3 00	27 00	10000640	92 60
33-04 CRACK DESCRIPTION	UNLOADED IN ONE PIECE WAVEFORM TRIANGULAR																		
33-04 COMMENTS	0 DEG /90 DEG CROSSPLY. STOPPED TEST - RUNOUT AT 10000640 CYCLES																		
35-06	1	11	1 0		0 2980	0 0820	0 0244	0 0249	1400	30 0000	6 80	994 0	99 4	894 4	40 00	4 00	36 00	32730	0 30
35-06 CRACK DESCRIPTION	IN UNIFORM SECTION,S,MULTIPLE INITIATIONS WAVEFORM TRIANGULAR																		
35-06 COMMENTS	0 DEG /P/M 45 DEG /90 DEG CROSSPLY.																		
35-04	1	9	1.0		0 2960	0 0815	0 0241	0 0246	1400	30.0000	6 80	738 0	73 8	664 2	30 00	3 00	27.00	-0	5 91
35-04 CRACK DESCRIPTION	IN UNIFORM SECTION,S,MULTIPLE INITIATIONS,P WAVEFORM TRIANGULAR																		
35-04 COMMENTS	0 DEG /P/M 45 DEG /90 DEG CROSSPLY TEST CYCLED AT ZERO LOAD, NI)638800 & (1355030 CYCLES																		
45-01	.1	11	1 0		0 3042	0 0758	0 0231	0.0235	1400	30 0000	6 80	705 0	70.5	634 5	30 00	3 00	27 00	5210	0 05
45-01 CRACK DESCRIPTION	IN UNIFORM SECTION,S,MULTIPLE INITIATIONS WAVEFORM. TRIANGULAR																		
45-01 COMMENTS	0 DEG /P/M 45 DEG /90 DEG CROSSPLY																		
45-08	1	10	1 0		0 3635	0 0753	0 0229	0 0233	1400	30 0000	6 80	582.5	58 3	524 3	25 00	2 50	22 50	10044100	93 02
45-08 CRACK DESCRIPTION	UNLOADED IN ONE PIECE WAVEFORM TRIANGULAR																		
45-08 COMMENTS	0 DEG /P/M 45 DEG/90 DEG. CROSSPLY STOPPED TEST - RUNOUT AT 10044100 CYCLES																		

APPENDIX C

Task III. Fatigue Crack Growth Data

TRANSVERSE FCGR

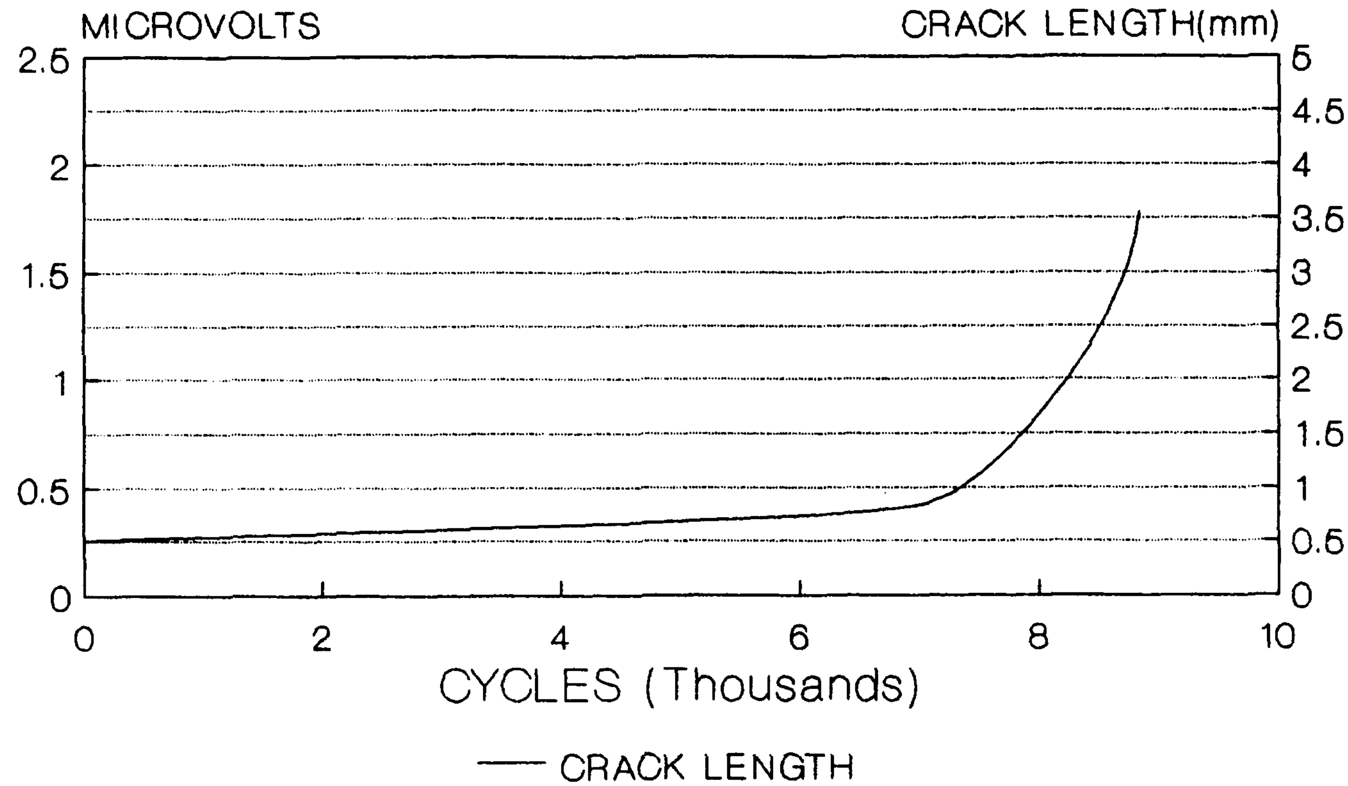
M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL TRANS.
TEMPERATURE (C): 25.55556
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 685.4545
MIN. LOAD, kg: 68.54546
LOAD RANGE, kg: 616.9091
CYCLE OFFSET: 0

SPECIMEN I.D.: A62-2
DRAWING NUMBER:
DATE: 07-02-89
MACHINE: 12
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 25.4839
THICKNESS (B), mm: 2.1209
NOTCH LENGTH, mm: .508
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	0.51	0.00	0.000	0.0	0.000E+00
6782	0.000	0.72	0.62	0.024	5.5	0.318E-07
7124	0.000	0.83	0.77	0.030	6.2	0.297E-06
7881	0.000	1.37	1.10	0.043	7.5	0.721E-06
8781	0.000	2.83	2.10	0.082	10.5	0.162E-05
8834	0.000	3.56	3.19	0.125	13.1	0.137E-04

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A62-2,200CPM,26C,R=.1

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL TRANS.
TEMPERATURE (C): 25.55556
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 703
MIN. LOAD, kg: 70.31818
LOAD RANGE, kg: 632.6818
CYCLE OFFSET: 0

SPECIMEN I.D.: A55-4
DRAWING NUMBER:
DATE: 07-02-89
MACHINE: 9
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 25.527
THICKNESS (B), mm: 2.0574
NOTCH LENGTH, mm: .508
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	0.51	0.00	0.000	0.0	0.000E+00
4680	0.000	0.51	0.51	0.020	5.3	0.000E+00

(Note: failed in grips for 4th time - too short to reload.)

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

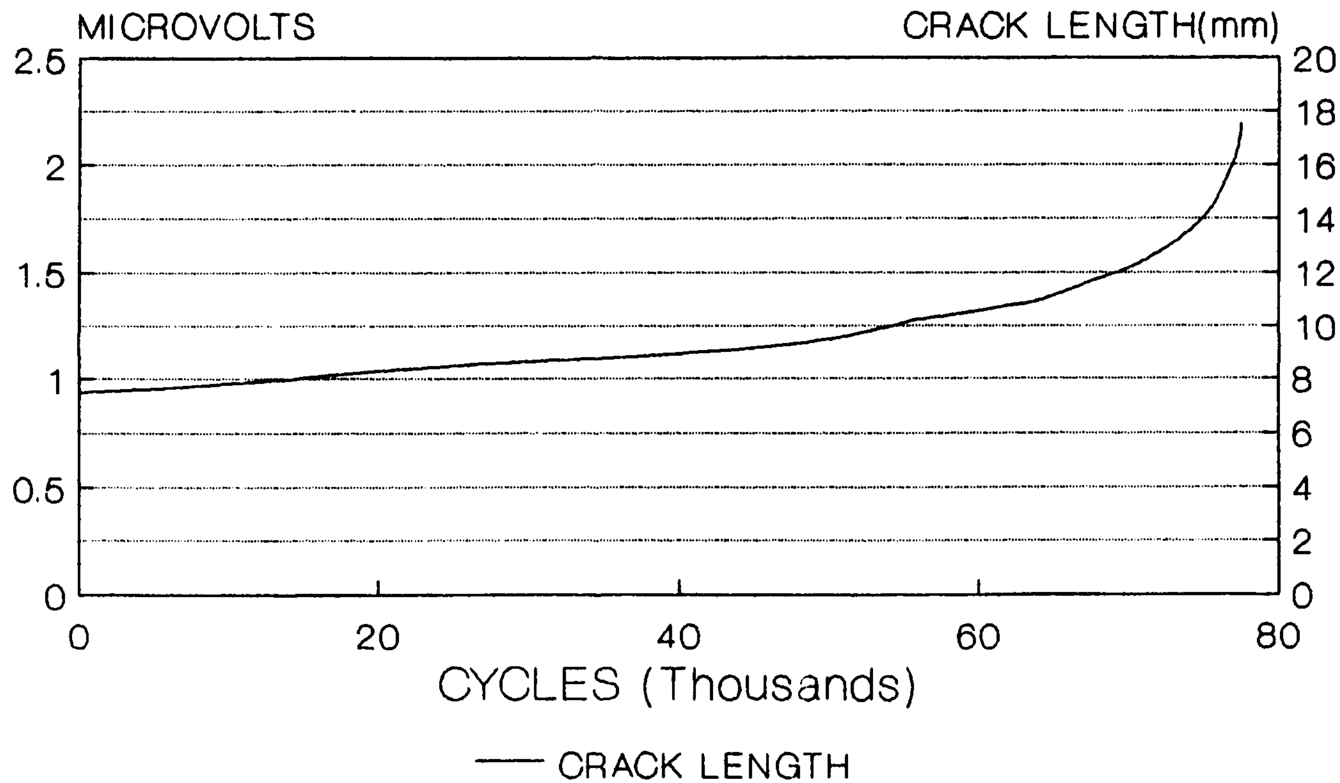
MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL TRANS.
TEMPERATURE (C): 315.5555
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 222.7273
MIN. LOAD, kg: 22.27273
LOAD RANGE, kg: 200.4545
CYCLE OFFSET: 0

SPECIMEN I.D.: A61-2
DRAWING NUMBER:
DATE: 06-29-89
MACHINE: 7
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 25.5016
THICKNESS (B), mm: 2.1082
NOTCH LENGTH, mm: 2.54
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	7.49	0.00	0.000	0.0	0.000E+00
4500	0.000	7.61	7.55	0.296	7.1	0.254E-07
6400	0.000	7.67	7.64	0.300	7.2	0.334E-07
9840	0.000	7.84	7.81	0.306	7.3	0.411E-07
12500	0.000	7.89	7.94	0.311	7.4	0.438E-07
18920	0.000	8.27	8.24	0.323	7.6	0.400E-07
22970	0.000	8.39	8.40	0.329	7.7	0.365E-07
27650	0.000	8.60	8.55	0.335	7.8	0.373E-07
34170	0.000	8.74	8.70	0.341	7.9	0.426E-07
42810	0.000	9.03	9.05	0.355	8.1	0.500E-07
49340	0.000	9.37	9.48	0.372	8.4	0.592E-07
54170	0.000	9.94	9.93	0.389	8.7	0.763E-07
55760	0.000	10.25	10.11	0.397	8.8	0.934E-07
58680	0.000	10.41	10.45	0.410	9.0	0.108E-06
61770	0.000	10.77	10.72	0.420	9.2	0.121E-06
63500	0.000	10.83	10.93	0.428	9.3	0.135E-06
65570	0.000	11.23	11.23	0.440	9.5	0.186E-06
68020	0.000	11.80	11.67	0.457	9.9	0.244E-06
70310	0.000	12.18	12.25	0.480	10.3	0.292E-06
73450	0.000	13.22	13.37	0.524	11.2	0.365E-06

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
75120	0.000	14.11	14.29	0.560	11.9	0.458E-06
75890	0.000	14.71	14.91	0.585	12.5	0.626E-06
76720	0.000	15.81	15.85	0.622	13.4	0.971E-06
77050	0.000	16.21	16.01	0.628	13.6	0.119E-05
77400	0.000	16.81	16.51	0.647	14.1	0.174E-05
77500	0.000	17.53	17.17	0.673	14.9	0.711E-05

MBRC
PD DROP,A VS CYCLE



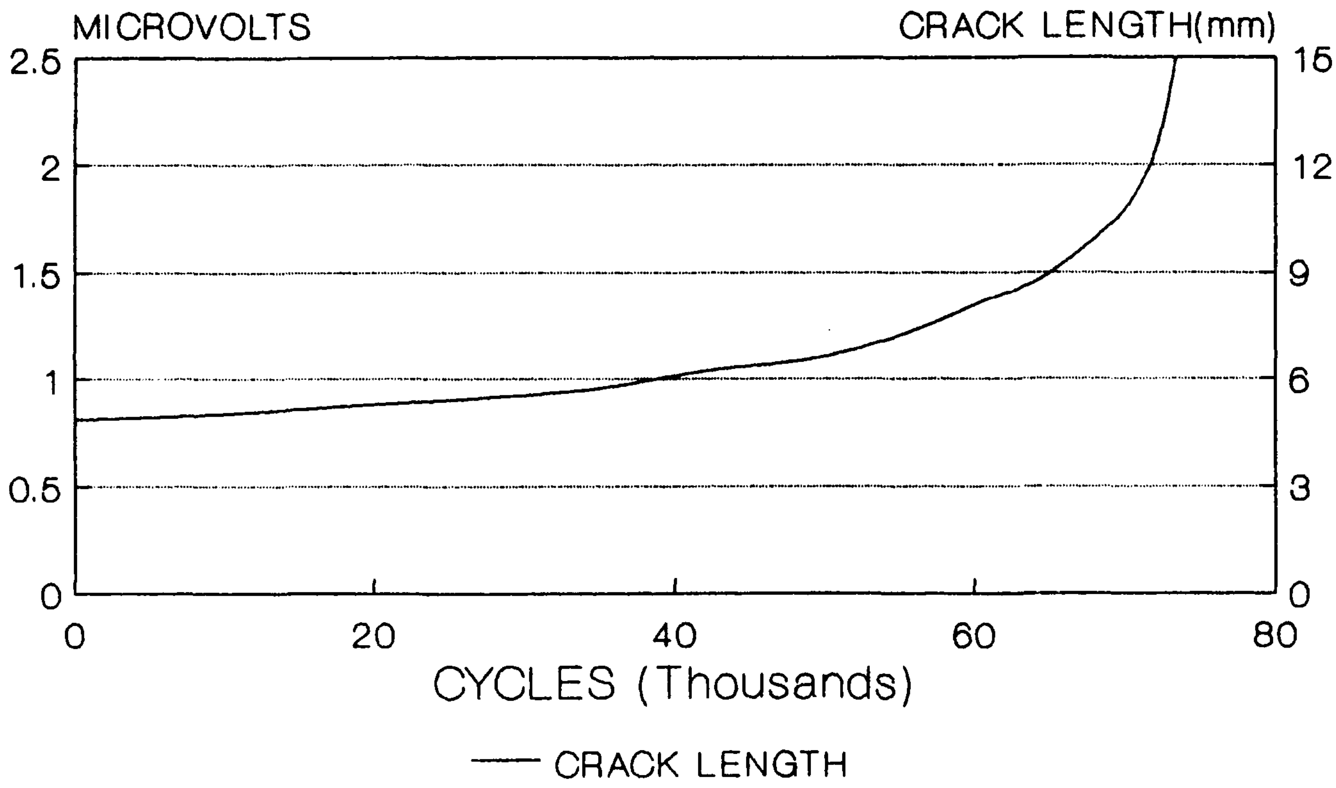
ALLISON,H838867,A61-2,200 CPM,316C,R=.1

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092	SPECIMEN I.D.: A58-2
CUSTOMER NAME: ALLISON	DRAWING NUMBER:
CONTACT: GAMBONE	DATE: 06-30-89
PURCHASE ORDER: H838867	MACHINE: 7
RELEASE:	WAVEFORM: TRIANGULAR
MATERIAL I.D.: SCS-6/TI3AL TRANS.	R-RATIO: .1
TEMPERATURE (C): 315.5555	A-RATIO: .8181818
FREQUENCY (Hz): 3.33	WIDTH (W), mm: 25.4
MAX. LOAD, kg: 290.9091	THICKNESS (B), mm: 2.032
MIN. LOAD, kg: 29.09091	NOTCH LENGTH, mm: 2.54
LOAD RANGE, kg: 261.8182	PROBE SPACING, mm: 0
CYCLE OFFSET: 0	SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	4.86	0.00	0.000	0.0	0.000E+00
1750	0.000	4.89	4.88	0.192	7.4	0.145E-07
7600	0.000	4.95	4.92	0.194	7.4	0.109E-07
11150	0.000	5.07	4.98	0.196	7.5	0.302E-07
31130	0.000	5.54	5.58	0.220	8.0	0.336E-07
36570	0.000	5.79	5.84	0.230	8.3	0.385E-07
41690	0.000	6.25	6.12	0.241	8.5	0.445E-07
45320	0.000	6.38	6.35	0.250	8.7	0.749E-07
48560	0.000	6.49	6.56	0.258	8.9	0.945E-07
53280	0.000	6.95	7.01	0.276	9.3	0.111E-06
58060	0.000	7.70	7.67	0.302	9.8	0.143E-06
60770	0.000	8.29	8.14	0.321	10.2	0.180E-06
63430	0.000	8.51	8.70	0.343	10.7	0.214E-06
66590	0.000	9.41	9.44	0.372	11.4	0.284E-06
68930	0.000	10.31	10.31	0.406	12.1	0.365E-06
69900	0.000	10.62	10.81	0.426	12.6	0.549E-06
71660	0.000	11.87	12.25	0.482	14.0	0.758E-06
72380	0.000	12.84	12.36	0.487	14.1	0.134E-05
73220	0.000	14.59	13.72	0.540	15.6	0.209E-05
73330	0.000	14.99	14.79	0.582	16.9	0.358E-05

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A58-2,200CPM,316C,R=.1

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

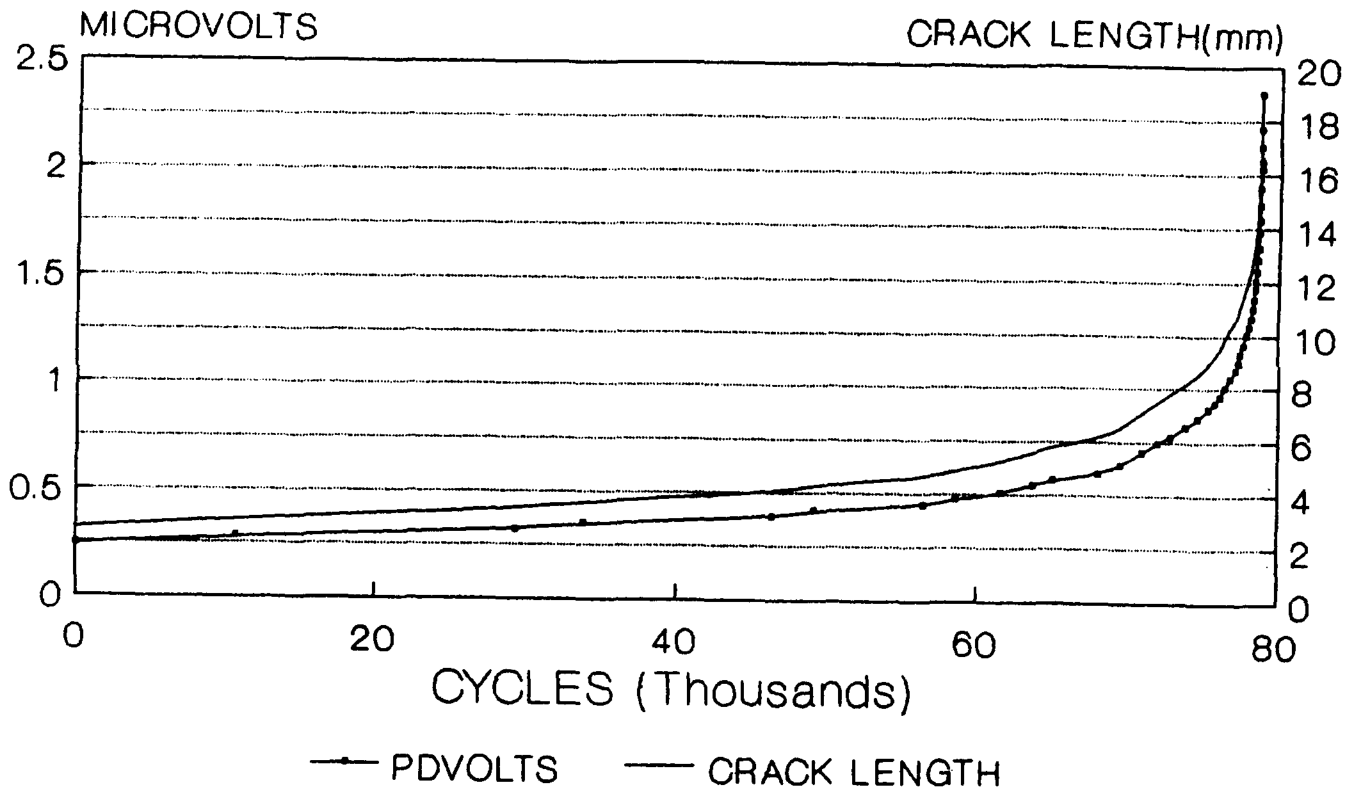
MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL TRANS.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 187.5
MIN. LOAD, kg: 18.77273
LOAD RANGE, kg: 168.7273
CYCLE OFFSET: 10200

SPECIMEN I.D.: A55-2
DRAWING NUMBER:
DATE: 06-30-89
MACHINE: 12
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 25.5143
THICKNESS (B), mm: 2.0701
NOTCH LENGTH, mm: 2.54
PROBE SPACING, mm: 1.379728E-02
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.241	2.54	0.00	0.000	0.0	0.000E+00
10739	0.282	2.92	2.73	0.107	3.4	0.355E-07
29384	0.317	3.30	3.11	0.122	3.6	0.204E-07
33839	0.349	3.63	3.56	0.140	3.9	0.353E-07
46379	0.386	3.99	4.09	0.160	4.2	0.393E-07
49184	0.416	4.29	4.22	0.165	4.3	0.541E-07
56444	0.447	4.60	4.72	0.185	4.6	0.611E-07
58589	0.475	4.88	4.87	0.191	4.7	0.912E-07
61559	0.507	5.21	5.22	0.205	4.9	0.103E-06
63704	0.544	5.56	5.55	0.218	5.0	0.142E-06
65024	0.570	5.82	5.72	0.224	5.1	0.165E-06
67994	0.599	6.12	6.24	0.245	5.4	0.201E-06
69479	0.640	6.50	6.56	0.257	5.6	0.239E-06
70881	0.699	7.06	7.00	0.274	5.8	0.280E-06
71954	0.742	7.47	7.44	0.292	6.1	0.370E-06
72779	0.773	7.77	7.78	0.305	6.2	0.406E-06
73785	0.817	8.18	8.19	0.321	6.5	0.429E-06
74594	0.857	8.53	8.55	0.335	6.7	0.470E-06
75287	0.900	8.92	8.93	0.350	6.9	0.541E-06
75749	0.932	9.19	9.23	0.362	7.0	0.669E-06

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
76079	0.961	9.45	9.51	0.373	7.2	0.828E-06
76385	1.004	9.83	9.81	0.384	7.4	0.966E-06
76665	1.046	10.19	10.11	0.396	7.5	0.111E-05
77075	1.088	10.54	10.60	0.415	7.8	0.123E-05
77325	1.123	10.82	10.92	0.428	8.0	0.138E-05
77425	1.163	11.15	11.07	0.434	8.1	0.153E-05
77645	1.202	11.48	11.49	0.450	8.3	0.183E-05
77835	1.254	11.89	11.86	0.465	8.6	0.203E-05
78005	1.291	12.17	12.20	0.478	8.8	0.212E-05
78135	1.329	12.45	12.52	0.491	9.0	0.257E-05
78235	1.374	12.80	12.82	0.503	9.2	0.306E-05
78295	1.418	13.11	13.07	0.512	9.3	0.399E-05
78385	1.468	13.46	13.52	0.530	9.7	0.489E-05
78415	1.504	13.72	13.67	0.536	9.8	0.560E-05
78475	1.549	14.02	14.01	0.549	10.0	0.639E-05
78535	1.606	14.40	14.43	0.566	10.3	0.783E-05
78575	1.658	14.76	14.78	0.579	10.6	0.894E-05
78615	1.731	15.21	15.27	0.599	11.0	0.116E-04
78635	1.787	15.54	15.57	0.610	11.3	0.155E-04
78655	1.858	15.98	15.95	0.625	11.6	0.184E-04
78675	1.935	16.41	16.40	0.643	12.0	0.220E-04
78695	2.026	16.89	16.88	0.662	12.5	0.245E-04
78705	2.063	17.09	17.13	0.672	12.7	0.301E-04
78715	2.129	17.42	17.26	0.676	12.9	0.330E-04
78725	2.211	17.83	17.63	0.691	13.3	0.406E-04
78735	2.373	18.57	18.20	0.713	14.0	0.737E-04

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A55-2,200CPM,649C,R=.1

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

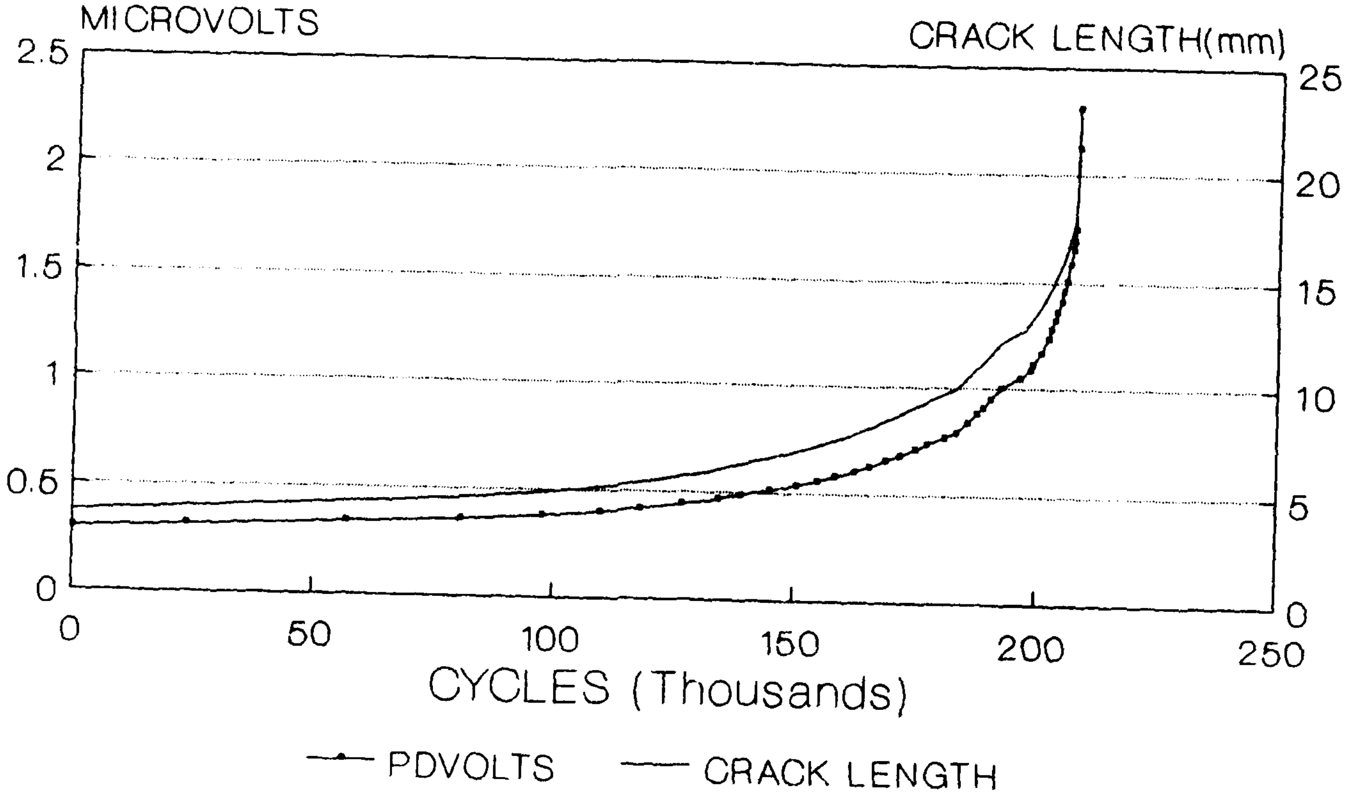
MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL TRANS.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 147.2727
MIN. LOAD, kg: 14.72727
LOAD RANGE, kg: 132.5455
CYCLE OFFSET: 82400

SPECIMEN I.D.: A62-4
DRAWING NUMBER:
DATE: 06-30-89
MACHINE: 12
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 25.5016
THICKNESS (B), mm: 2.159
NOTCH LENGTH, mm: 2.54
PROBE SPACING, mm: 1.36525
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.294	3.71	0.00	0.000	0.0	0.000E+00
23712	0.313	3.99	3.85	0.151	3.1	0.118E-07
56751	0.336	4.29	4.14	0.162	3.2	0.923E-08
80703	0.356	4.57	4.62	0.181	3.4	0.135E-07
97579	0.379	4.88	4.91	0.192	3.5	0.161E-07
109743	0.399	5.16	5.18	0.203	3.6	0.219E-07
118158	0.420	5.41	5.42	0.212	3.7	0.292E-07
126705	0.442	5.71	5.72	0.224	3.9	0.370E-07
134460	0.466	6.02	6.07	0.233	4.0	0.443E-07
138849	0.491	6.35	6.29	0.247	4.1	0.495E-07
144729	0.513	6.63	6.62	0.260	4.2	0.558E-07
150333	0.537	6.93	6.96	0.273	4.4	0.614E-07
154722	0.559	7.21	7.22	0.287	4.5	0.651E-07
158418	0.582	7.49	7.49	0.294	4.6	0.742E-07
162444	0.607	7.80	7.82	0.307	4.7	0.837E-07
165348	0.631	8.10	8.09	0.317	4.8	0.913E-07
168714	0.658	8.41	8.41	0.330	5.0	0.954E-07
171618	0.682	8.71	8.72	0.342	5.1	0.103E-06
174924	0.711	9.04	9.06	0.355	5.2	0.105E-06
177129	0.737	9.35	9.28	0.364	5.3	0.116E-06

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
180625	0.767	9.63	9.70	0.380	5.5	0.131E-06
183399	0.794	9.98	10.06	0.394	5.6	0.152E-06
185626	0.838	10.46	10.45	0.410	5.8	0.174E-06
187458	0.881	10.92	10.87	0.426	6.0	0.223E-06
188910	0.909	11.23	11.31	0.444	6.2	0.215E-06
190362	0.948	11.63	11.65	0.457	6.4	0.198E-06
192309	1.004	12.19	12.05	0.473	6.5	0.193E-06
196335	1.047	12.62	12.74	0.500	6.9	0.194E-06
198460	1.086	13.00	13.14	0.515	7.1	0.215E-06
198909	1.113	13.26	13.21	0.518	7.1	0.240E-06
200512	1.167	13.74	13.74	0.539	7.4	0.347E-06
202209	1.241	14.40	14.46	0.567	7.8	0.415E-06
202720	1.282	14.76	14.69	0.576	7.9	0.425E-06
203644	1.326	15.11	15.15	0.594	8.2	0.481E-06
204073	1.365	15.42	15.37	0.603	8.4	0.528E-06
204997	1.409	15.77	15.85	0.621	8.7	0.569E-06
205360	1.458	16.13	16.06	0.630	8.8	0.659E-06
206053	1.506	16.48	16.53	0.648	9.1	0.697E-06
206647	1.585	17.04	17.02	0.667	9.5	0.826E-06
207142	1.653	17.48	17.50	0.686	9.9	0.120E-05
207439	1.692	17.73	18.00	0.706	10.4	0.188E-05
207670	1.750	18.08	17.91	0.702	10.3	0.134E-05
207934	2.126	20.04	19.06	0.748	11.4	0.741E-05
208066	2.312	20.83	20.43	0.801	13.2	0.597E-05

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A62-4,200CPM,649C,R=.1

LONGITUDINAL FCGR

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 25.55556
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 1965.909
MIN. LOAD, kg: 196.5909
LOAD RANGE, kg: 1769.318
CYCLE OFFSET: 0

SPECIMEN I.D.: A100-6
DRAWING NUMBER:
DATE: 07-02-89
MACHINE: 11
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 1.9812
NOTCH LENGTH, mm: 1.143
PROBE SPACING, mm: 1.27
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
575921	0.000	10.72	0.00	0.000	0.0	0.000E+00
762940	0.000	11.42	11.07	0.396	78.7	0.377E-08
809090	0.000	12.01	11.72	0.419	82.3	0.129E-07
900800	0.000	12.70	12.36	0.442	85.9	0.748E-08

Increased load to 2162.7 Kg at cycle 900800. Specimen failed at cycle 901301.

M.B.R.C. TEST REPORTING

CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 25.55556
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 4295.455
MIN. LOAD, kg: 0
LOAD RANGE, kg: 4295.455
CYCLE OFFSET: 0

SPECIMEN I.D.: A98-6
DRAWING NUMBER:
DATE: ~~[illegible]~~ 03-29-89
MACHINE: 12
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181812
WIDTH (W), mm: 25.0571
THICKNESS (B), mm: 2.0828
NOTCH LENGTH, mm: 2.8194
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	7.53	0.00	0.000	0.0	0.000E+00
Tensile Pull → 1	0.000	7.53	7.53	0.301	157.7	0.000E+00

Test stopped after repeated increases in load did not produce horizontal growth and tensile pulled per M.L. Gambone. Failed in gripping region.

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

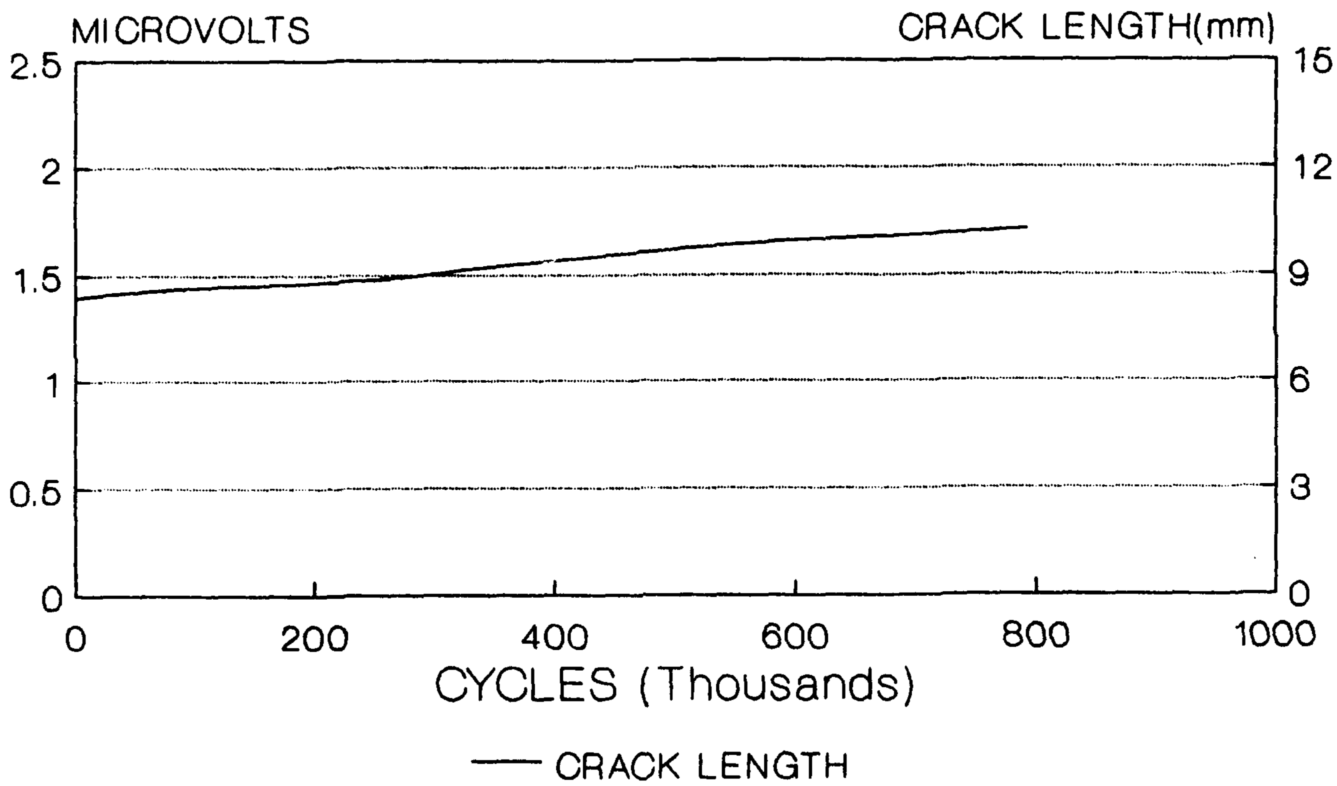
MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 25.55556
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 2105
MIN. LOAD, kg: 1052.5
LOAD RANGE, kg: 1052.5
CYCLE OFFSET: 0

SPECIMEN I.D.: A101-6
DRAWING NUMBER:
DATE: 07-05-89
MACHINE: 2
WAVEFORM: TRIANGULAR
R-RATIO: .5
A-RATIO: .3333333
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 1.9431
NOTCH LENGTH, mm: 1.27
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	8.38	0.00	0.000	0.0	0.000E+00
76800	0.000	8.64	8.51	0.305	39.6	0.331E-08
133980	0.000	8.70	8.67	0.310	40.1	0.111E-08
248730	0.000	8.85	8.92	0.319	40.9	0.210E-08
277260	0.000	8.95	8.96	0.321	41.0	0.250E-08
304400	0.000	9.03	9.06	0.324	41.3	0.295E-08
336500	0.000	9.21	9.20	0.329	41.7	0.279E-08
433980	0.000	9.51	9.53	0.341	42.8	0.251E-08
604600	0.000	10.02	9.77	0.350	43.5	0.298E-08
718740	0.000	10.11	10.06	0.360	44.5	0.779E-09
792590	0.000	10.26	10.19	0.365	44.9	0.206E-08

Specimen growing vertically, stopped and tensile pulled for U.T.S. = 63.7 ksi.

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A101-6,200CPM,26C,R=.5

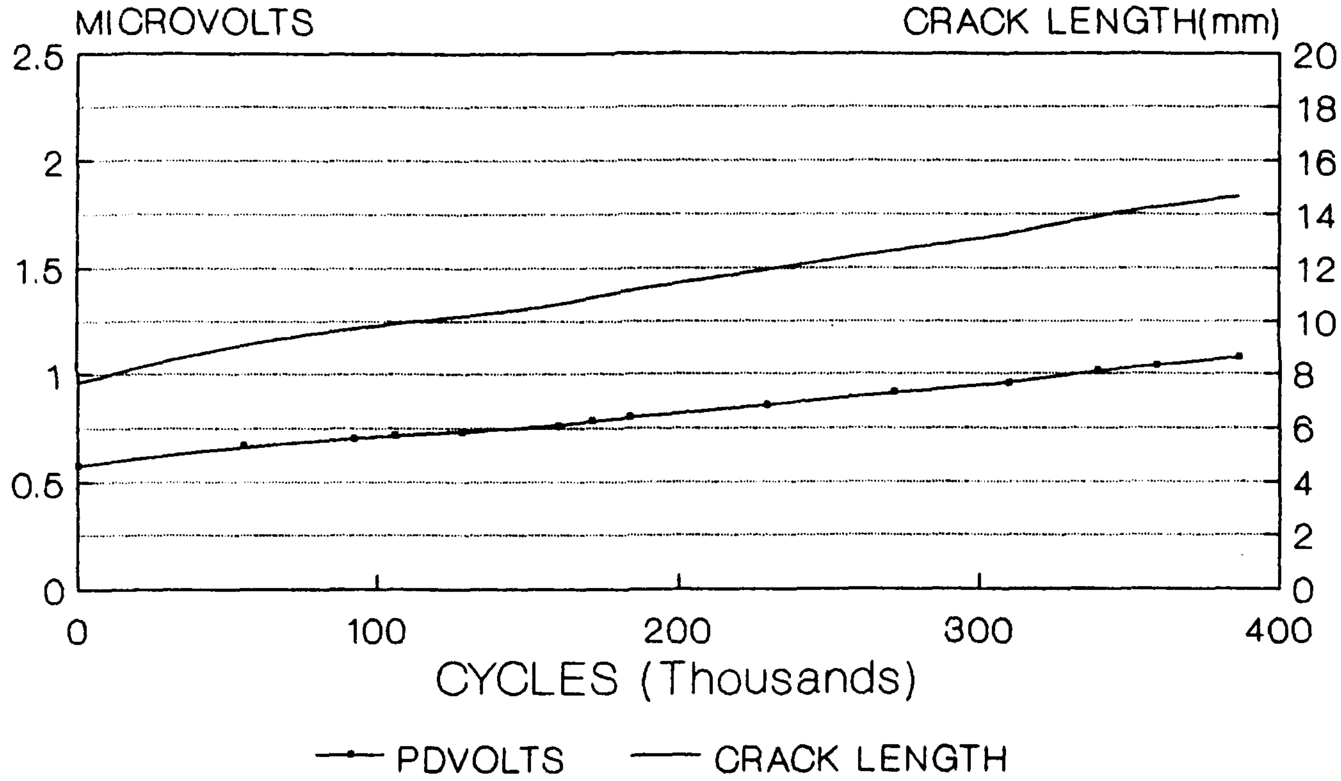
M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 25.55556
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 2924.091
MIN. LOAD, kg: 1462.273
LOAD RANGE, kg: 1461.818
CYCLE OFFSET: 0

SPECIMEN I.D.: A105-6
DRAWING NUMBER:
DATE: 07-05-89
MACHINE: 11
WAVEFORM: TRIANGULAR
R-RATIO: .5
A-RATIO: .3333333
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 2.1209
NOTCH LENGTH, mm: 1.143
PROBE SPACING, mm: 4.953
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.577	7.70	0.00	0.000	0.0	0.000E+00
55220	0.668	9.19	8.45	0.302	50.1	0.271E-07
92040	0.703	9.73	9.46	0.339	54.2	0.145E-07
105800	0.716	9.93	9.96	0.357	56.2	0.177E-07
128170	0.733	10.19	10.21	0.365	57.2	0.146E-07
160250	0.760	10.59	10.69	0.383	59.2	0.160E-07
171220	0.782	10.92	10.88	0.390	60.0	0.168E-07
183900	0.798	11.15	11.12	0.398	61.0	0.171E-07
229403	0.853	11.91	11.88	0.425	64.3	0.179E-07
271784	0.910	12.65	12.62	0.452	67.5	0.178E-07
309707	0.954	13.21	13.32	0.477	70.7	0.177E-07
339042	1.014	13.97	13.59	0.486	72.0	0.260E-07
358550	1.039	14.25	14.11	0.505	74.5	0.143E-07
386400	1.076	14.68	14.47	0.518	76.3	0.155E-07

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A105-6,200CPM,26C,R=.5

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 25.55556
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 3080
MIN. LOAD, kg: 2464.091
LOAD RANGE, kg: 615.9091
CYCLE OFFSET: 0

SPECIMEN I.D.: A103-1
DRAWING NUMBER:
DATE: 07-06-89
MACHINE: 11
WAVEFORM: TRIANGULAR
R-RATIO: .8
A-RATIO: .1111111
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 1.9558
NOTCH LENGTH, mm: 1.143
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	8.38	0.00	0.000	0.0	0.000E+00
1	0.000	8.38	8.38	0.300	22.8	0.000E+00

M.B.R.C. TEST REPORTING

CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

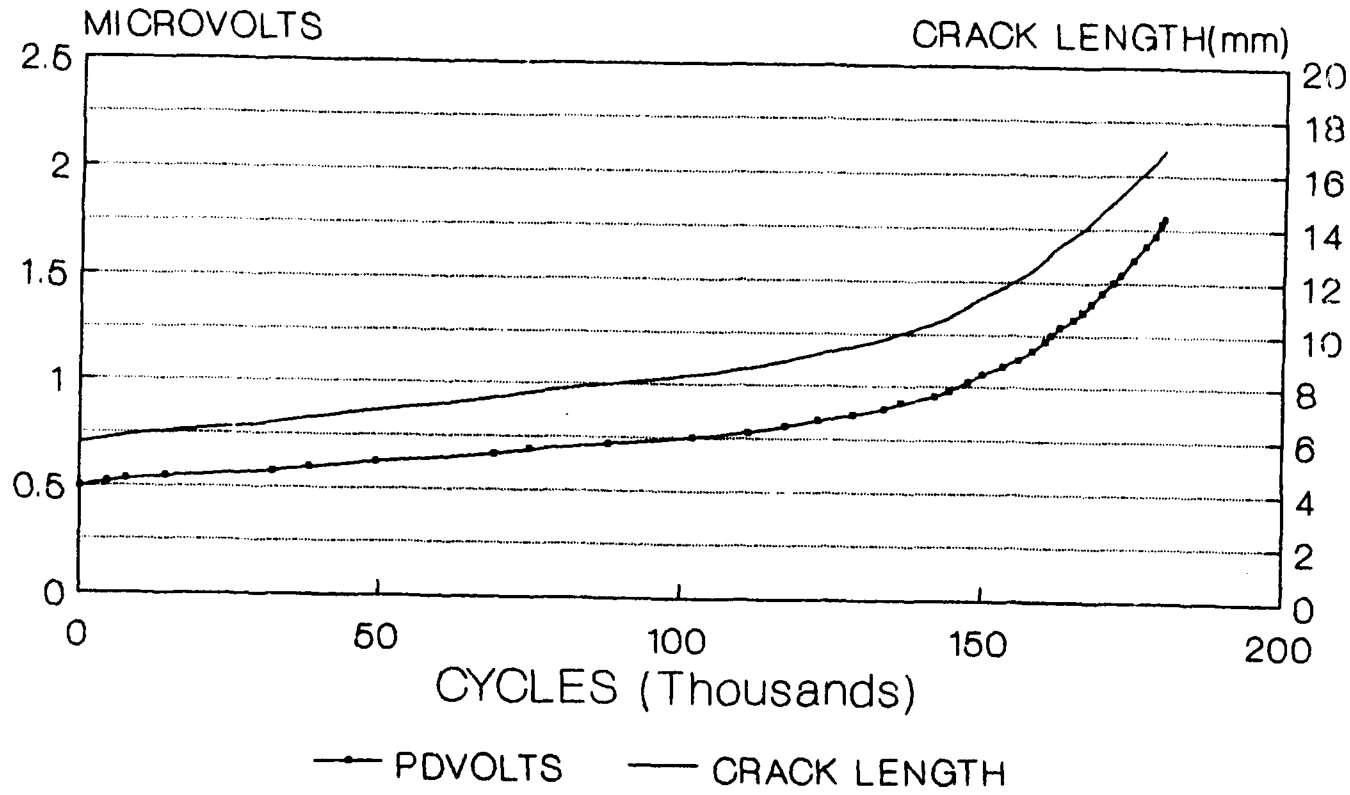
MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 315.5555
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 1994.091
MIN. LOAD, kg: 199.4091
LOAD RANGE, kg: 1794.682
CYCLE OFFSET: 565471

SPECIMEN I.D.: A98-1
DRAWING NUMBER:
DATE: 06-30-89
MACHINE: 1
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 25.0952
THICKNESS (B), mm: 2.1082
NOTCH LENGTH, mm: 3.302
PROBE SPACING, mm: 2.159
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.495	5.61	0.00	0.000	0.0	0.000E+00
4720	0.521	5.74	5.68	0.226	54.3	0.269E-07
7690	0.532	5.89	5.82	0.232	55.1	0.513E-07
14455	0.546	6.05	6.00	0.239	56.2	0.252E-07
32110	0.572	6.35	6.44	0.257	58.7	0.248E-07
38215	0.597	6.63	6.58	0.262	59.5	0.258E-07
49270	0.622	6.91	6.88	0.274	61.2	0.269E-07
69070	0.661	7.37	7.45	0.297	64.5	0.278E-07
74845	0.689	7.67	7.60	0.303	65.4	0.273E-07
87880	0.717	7.98	7.96	0.317	67.4	0.286E-07
101905	0.749	8.33	8.36	0.333	69.8	0.318E-07
111145	0.775	8.61	8.67	0.345	71.6	0.335E-07
117250	0.805	8.92	8.92	0.355	73.0	0.396E-07
122695	0.834	9.22	9.18	0.366	74.6	0.489E-07
128470	0.862	9.50	9.51	0.379	76.6	0.571E-07
133585	0.887	9.75	9.81	0.391	78.4	0.624E-07
136489	0.918	10.06	9.99	0.398	79.5	0.716E-07
142000	0.951	10.39	10.44	0.416	82.3	0.865E-07
144475	0.978	10.67	10.70	0.426	83.9	0.102E-06
147445	1.020	11.05	11.03	0.439	86.0	0.108E-06

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
149920	1.058	11.40	11.36	0.453	88.1	0.125E-06
153220	1.096	11.76	11.76	0.469	90.8	0.133E-06
155695	1.129	12.04	12.08	0.481	93.0	0.142E-06
158005	1.172	12.42	12.44	0.496	95.4	0.156E-06
160150	1.219	12.83	12.85	0.512	98.4	0.175E-06
161024	1.249	13.08	13.04	0.520	99.8	0.184E-06
162575	1.286	13.39	13.33	0.531	102.0	0.184E-06
164770	1.321	13.67	13.71	0.546	104.9	0.183E-06
166321	1.359	13.97	13.98	0.557	107.0	0.183E-06
167905	1.400	14.27	14.27	0.569	109.4	0.189E-06
169553	1.448	14.63	14.61	0.582	112.3	0.207E-06
171518	1.500	15.01	15.02	0.599	115.9	0.211E-06
172690	1.535	15.27	15.29	0.609	118.2	0.212E-06
174785	1.606	15.75	15.72	0.626	122.3	0.219E-06
176815	1.672	16.18	16.18	0.645	126.9	0.227E-06
178399	1.719	16.48	16.33	0.651	128.5	0.192E-06
179356	1.773	16.81	16.65	0.663	132.0	0.345E-06
179884	1.797	16.94	16.88	0.673	134.5	0.241E-06

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A98-1,200 CPM,316C,R=.1

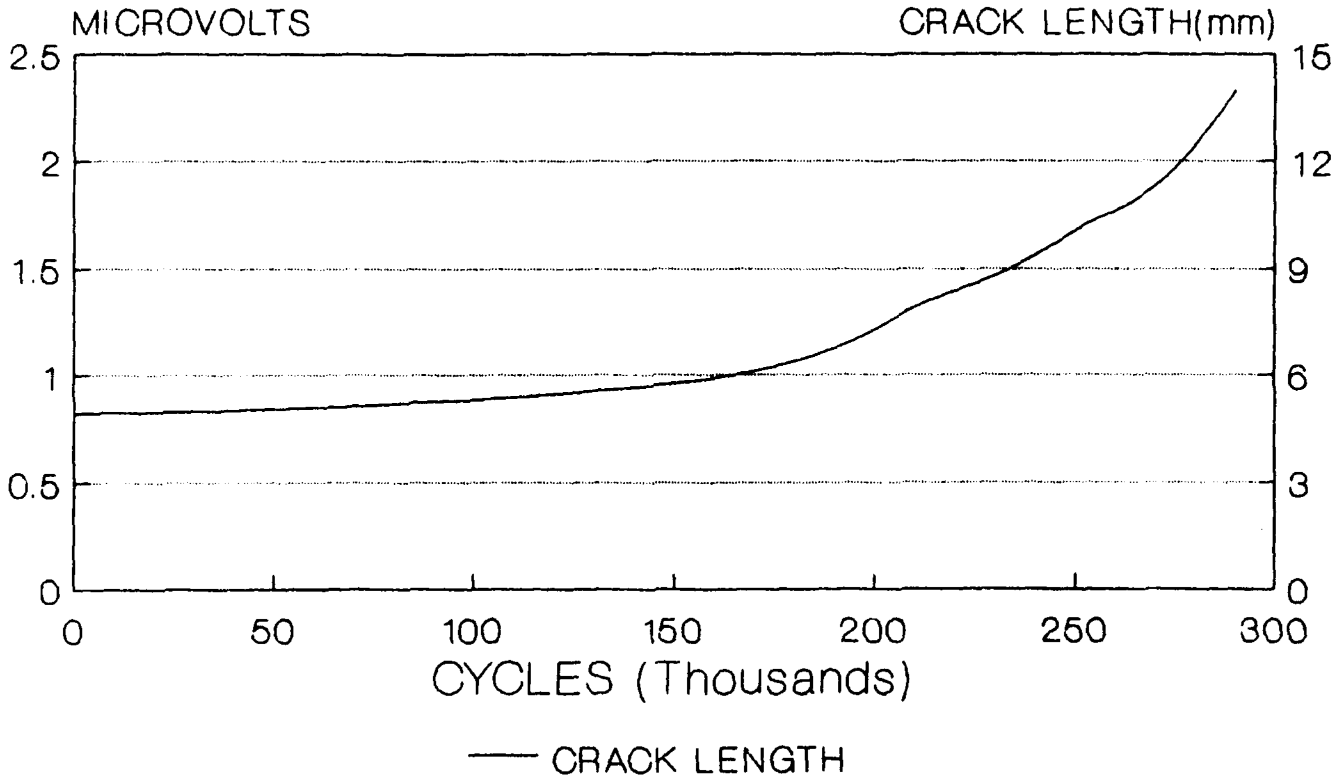
M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 315.5555
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 2145.455
MIN. LOAD, kg: 214.5455
LOAD RANGE, kg: 1930.909
CYCLE OFFSET: 0

SPECIMEN I.D.: A104-6
DRAWING NUMBER:
DATE: 06-29-89
MACHINE: 4
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 2.0574
NOTCH LENGTH, mm: 1.27
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	4.93	0.00	0.000	0.0	0.000E+00
44600	0.000	4.99	4.96	0.177	49.1	0.142E-08
83520	0.000	5.18	5.09	0.182	49.9	0.489E-08
182420	0.000	5.85	6.75	0.242	59.1	0.170E-07
209010	0.000	8.05	7.63	0.273	63.8	0.246E-07
225880	0.000	8.51	8.44	0.302	68.2	0.320E-07
243640	0.000	9.58	9.71	0.348	75.1	0.598E-07
255190	0.000	10.46	10.22	0.366	77.9	0.694E-07
261580	0.000	10.57	10.52	0.376	79.6	0.159E-07
277240	0.000	11.84	11.20	0.401	83.5	0.811E-07
289940	0.000	13.97	12.90	0.462	93.7	0.168E-06

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A104-6,200 CPM,316C,R=.1

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

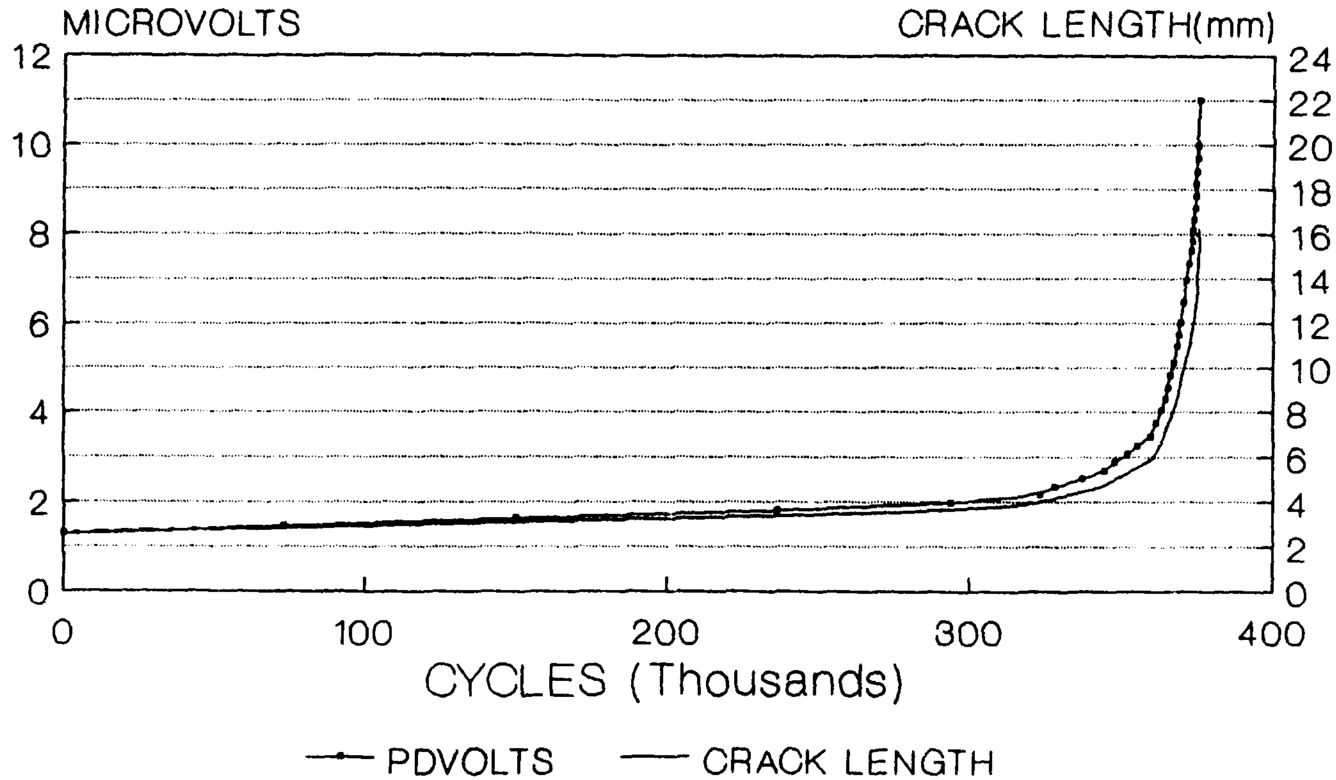
MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 2088.182
MIN. LOAD, kg: 208.6364
LOAD RANGE, kg: 1879.545
CYCLE OFFSET: 769965

SPECIMEN I.D.: A97-6
DRAWING NUMBER:
DATE: 07-02-89
MACHINE: 3
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 2.1463
NOTCH LENGTH, mm: 2.5654
PROBE SPACING, mm: .254
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	1.294	2.57	0.00	0.000	0.0	0.000E+00
73433	1.463	2.84	2.71	0.097	32.7	0.380E-08
149828	1.628	3.10	2.97	0.106	34.5	0.332E-08
236288	1.798	3.35	3.43	0.123	37.3	0.419E-08
293543	1.967	3.61	3.79	0.136	39.4	0.502E-08
322731	2.156	3.91	4.14	0.148	41.4	0.709E-08
327698	2.338	4.19	4.21	0.151	41.7	0.133E-07
337103	2.510	4.44	4.46	0.160	43.2	0.277E-07
344033	2.684	4.70	4.78	0.171	44.9	0.477E-07
347333	2.882	5.00	4.96	0.178	45.9	0.532E-07
351623	3.062	5.26	5.25	0.188	47.4	0.712E-07
354741	3.248	5.54	5.50	0.197	48.7	0.937E-07
359213	3.450	5.82	5.99	0.214	51.2	0.110E-06
361193	3.746	6.25	6.29	0.225	52.8	0.149E-06
362909	4.045	6.68	6.68	0.239	54.3	0.199E-06
363899	4.283	7.01	7.01	0.251	56.4	0.300E-06
364905	4.541	7.37	7.35	0.263	58.2	0.345E-06
365928	4.816	7.75	7.73	0.277	60.1	0.389E-06
367001	5.100	8.13	8.16	0.292	62.2	0.419E-06
368024	5.467	8.61	8.62	0.308	64.5	0.472E-06

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
368667	5.735	8.97	8.95	0.320	66.2	0.532E-06
369294	5.996	9.30	9.33	0.334	68.1	0.581E-06
370169	6.466	9.88	9.87	0.353	70.9	0.608E-06
371093	6.961	10.46	10.45	0.374	73.9	0.611E-06
371852	7.330	10.90	10.91	0.391	76.4	0.611E-06
372371	7.618	11.23	11.22	0.401	78.0	0.603E-06
372841	7.849	11.48	11.49	0.411	79.5	0.624E-06
373261	8.090	11.73	11.75	0.421	80.9	0.695E-06
373611	8.329	11.99	12.02	0.430	82.4	0.799E-06
373901	8.582	12.27	12.30	0.440	83.9	0.970E-06
374091	8.848	12.55	12.52	0.448	85.2	0.116E-05
374291	9.118	12.80	12.80	0.458	86.3	0.133E-05
374491	9.391	13.08	12.94	0.463	87.7	0.254E-05
374681	9.686	13.36	13.22	0.473	89.3	0.147E-05
374861	9.984	13.64	13.50	0.483	91.0	0.155E-05
375360	11.000	16.26	14.95	0.535	100.1	0.524E-05

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A97-6,200CPM,649C,R=.1

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

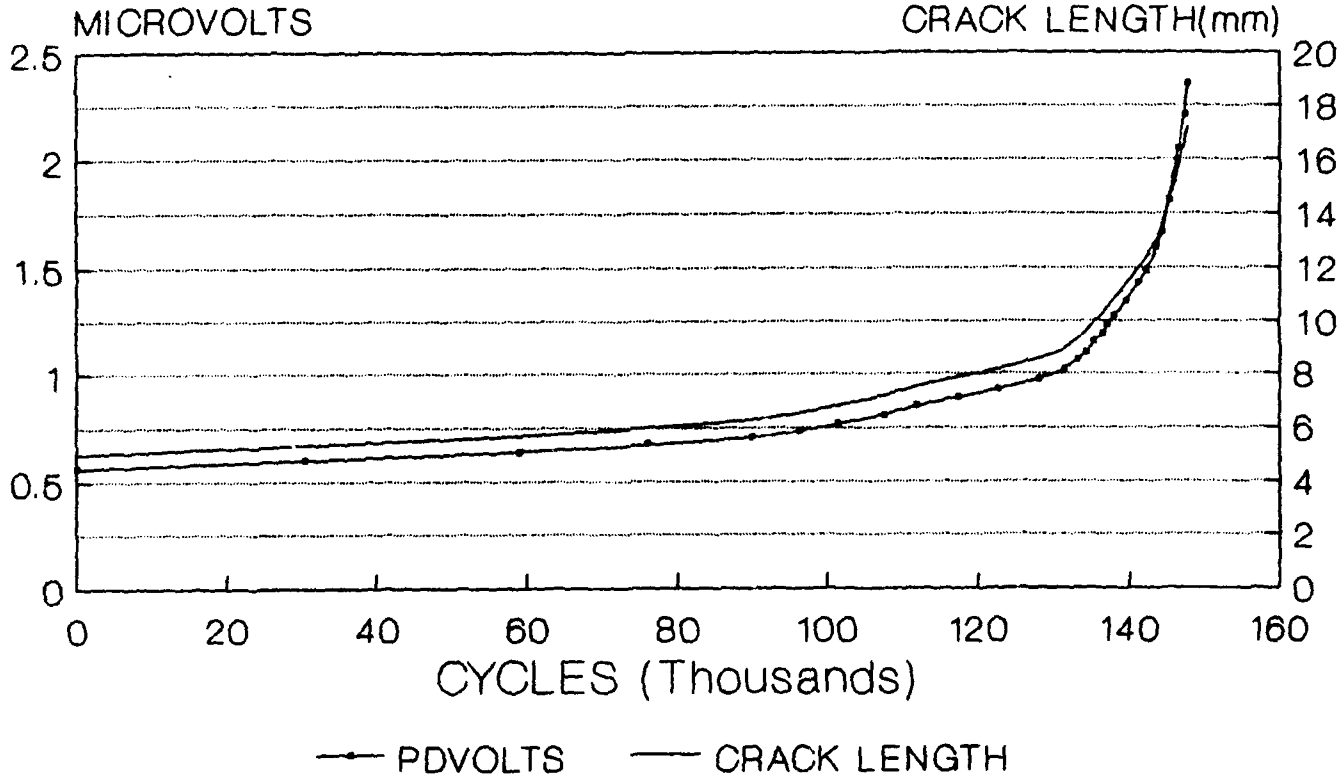
MBRC JOB: 010-072
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 1298.182
MIN. LOAD, kg: 129.8182
LOAD RANGE, kg: 1168.364
CYCLE OFFSET: 472524

SPECIMEN I.D.: A99-1
DRAWING NUMBER:
DATE: 07-02-89
MACHINE: 12
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 25.4
THICKNESS (B), mm: 2.0574
NOTCH LENGTH, mm: 1.524
PROBE SPACING, mm: 1.222502
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.564	5.03	0.00	0.000	0.0	0.000E+00
30347	0.600	5.36	5.19	0.204	33.9	0.109E-07
58892	0.636	5.66	5.51	0.217	35.1	0.107E-07
76052	0.671	5.99	6.02	0.237	37.1	0.160E-07
89912	0.701	6.25	6.37	0.251	38.4	0.218E-07
96347	0.732	6.53	6.57	0.259	39.1	0.332E-07
101412	0.766	6.81	6.79	0.267	40.0	0.466E-07
107567	0.806	7.16	7.20	0.283	41.5	0.604E-07
111857	0.849	7.52	7.48	0.295	42.6	0.642E-07
117302	0.889	7.87	7.84	0.308	43.9	0.680E-07
122582	0.923	8.15	8.18	0.322	45.2	0.752E-07
127862	0.970	8.53	8.62	0.339	46.9	0.824E-07
131228	1.015	8.89	9.01	0.355	48.4	0.105E-06
132977	1.063	9.27	9.31	0.367	49.5	0.148E-06
134033	1.096	9.52	9.53	0.375	50.4	0.217E-06
135267	1.151	9.96	9.91	0.390	51.9	0.289E-06
136442	1.188	10.24	10.29	0.405	53.4	0.324E-06
137085	1.230	10.54	10.52	0.414	54.3	0.344E-06
137927	1.268	10.82	10.81	0.425	55.5	0.353E-06
139478	1.339	11.35	11.34	0.446	57.8	0.384E-06

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
141095	1.426	11.96	11.94	0.470	60.4	0.403E-06
142184	1.481	12.34	12.38	0.488	62.4	0.461E-06
143570	1.593	13.08	13.09	0.516	65.7	0.600E-06
144312	1.662	13.51	13.58	0.535	68.1	0.752E-06
145269	1.807	14.38	14.40	0.567	72.3	0.885E-06
146424	2.048	15.72	15.05	0.592	75.9	0.117E-05
147249	2.206	16.54	16.13	0.635	82.5	0.985E-06
147678	2.352	17.22	16.88	0.664	87.7	0.160E-05

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A99-1,200CPM,649C,R=.1

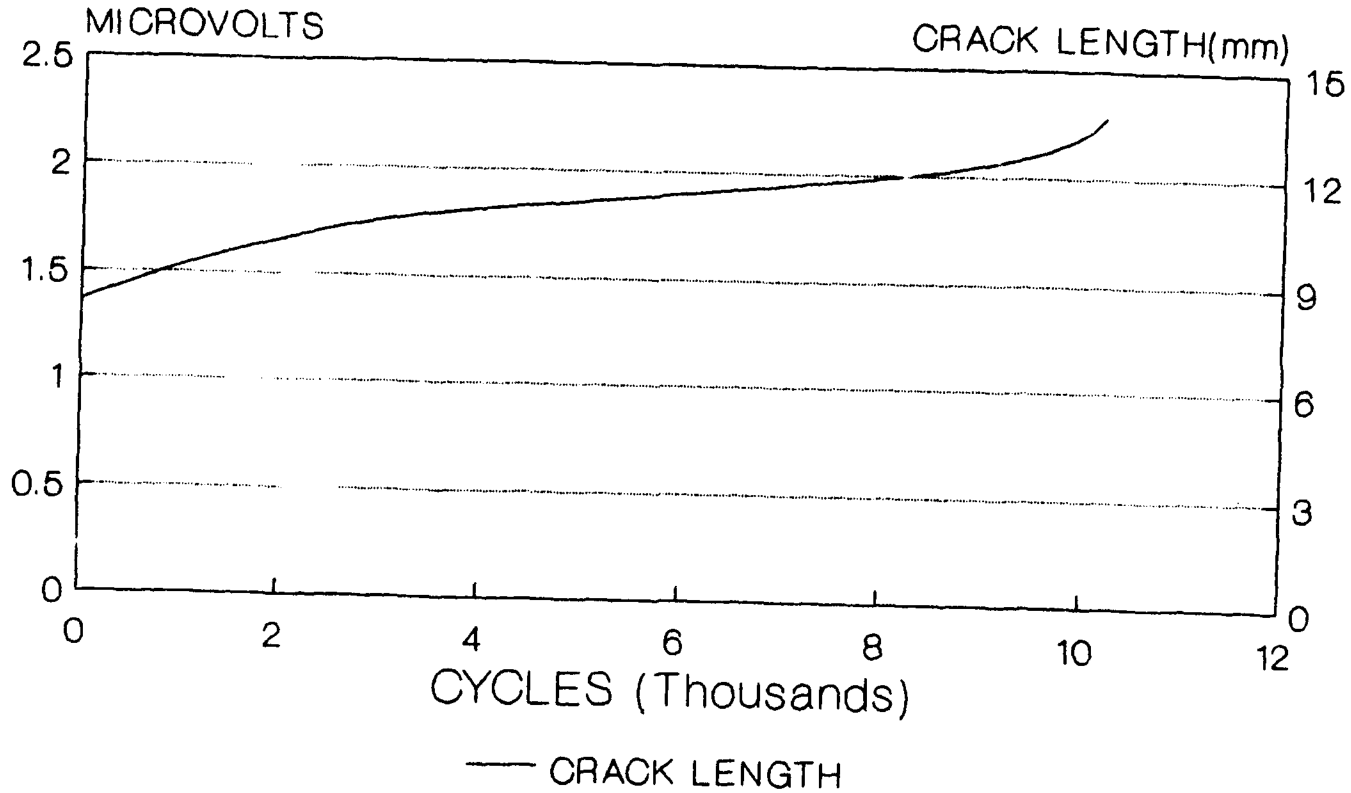
M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 2040.909
MIN. LOAD, kg: 1020.455
LOAD RANGE, kg: 1020.455
CYCLE OFFSET: 0

SPECIMEN I.D.: A104-1
DRAWING NUMBER:
DATE: 07-05-89
MACHINE: 2
WAVEFORM: TRIANGULAR
R-RATIO: .5
A-RATIO: .3333333
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 2.0574
NOTCH LENGTH, mm: 1.27
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	8.19	0.00	0.000	0.0	0.000E+00
2095	0.000	10.46	9.33	0.334	38.6	0.109E-05
4783	0.000	11.05	10.76	0.385	42.8	0.217E-06
6780	0.000	11.61	11.33	0.405	44.5	0.280E-06
9920	0.000	12.40	12.00	0.430	46.6	0.251E-06
10199	0.000	13.72	13.06	0.467	50.0	0.473E-05

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A104-1,200CPM,649C,R=.5

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 2943.182
MIN. LOAD, kg: 0
LOAD RANGE, kg: 2943.182
CYCLE OFFSET: 0

SPECIMEN I.D.: A101-1
DRAWING NUMBER:
DATE: 07-05-89
MACHINE: 2
WAVEFORM: TRIANGULAR
R-RATIO: .5
A-RATIO: .3333333
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 1.9304
NOTCH LENGTH, mm: 1.016
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

	CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
	0	0.000	7.21	0.00	0.000	0.0	0.000E+00
Tensile Pull	1	0.000	7.21	7.21	0.258	100.0	0.000E+00

Specimen growing vertically, tensile pulled for U.T.S. = 76.8 ksi.

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 2143.182
MIN. LOAD, kg: 1714.545
LOAD RANGE, kg: 428.6364
CYCLE OFFSET: 0

SPECIMEN I.D.: A97-1
DRAWING NUMBER:
DATE: 07-06-89
MACHINE: A97-1
WAVEFORM: TRIANGULAR
R-RATIO: .8
A-RATIO: .1111111
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 2.1463
NOTCH LENGTH, mm: 1.143
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	7.91	0.00	0.000	0.0	0.000E+00
1060	0.000	8.56	8.24	0.295	14.3	0.611E-06

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 1744.545
MIN. LOAD, kg: 1395.909
LOAD RANGE, kg: 348.6364
CYCLE OFFSET: 0

SPECIMEN I.D.: A100-1
DRAWING NUMBER:
DATE: 07-07-89
MACHINE: 12
WAVEFORM: TRIANGULAR
R-RATIO: .8
A-RATIO: .1111111
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 1.9685
NOTCH LENGTH, mm: 1.143
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	7.90	0.00	0.000	0.0	0.000E+00
6629	0.000	7.99	7.94	0.284	12.4	0.134E-07
58330	0.000	8.14	8.06	0.289	12.5	0.295E-08
110510	0.000	8.18	8.16	0.292	12.6	0.730E-09
212675	0.000	8.23	8.20	0.294	12.6	0.497E-09

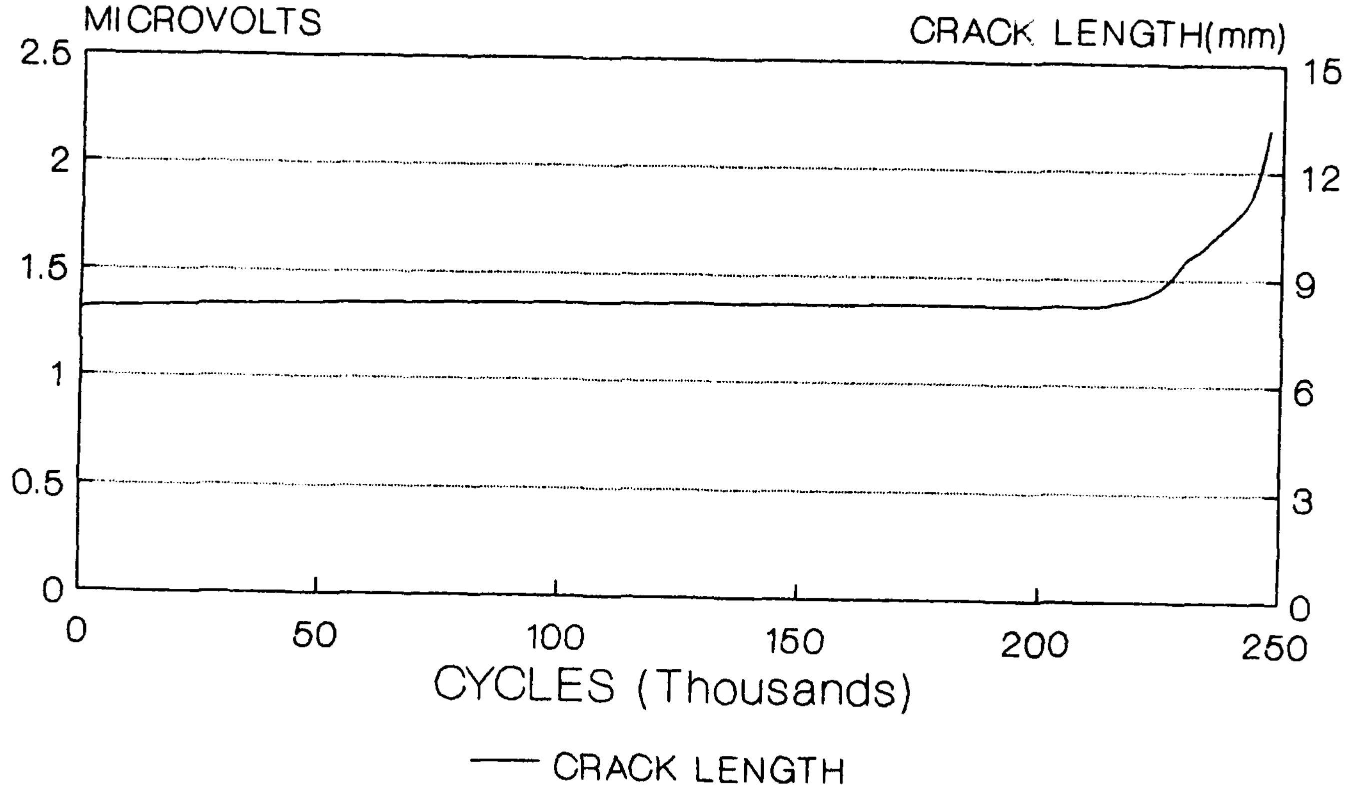
M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): 3.33
MAX. LOAD, kg: 2132.727
MIN. LOAD, kg: 1705.909
LOAD RANGE, kg: 426.8182
CYCLE OFFSET: 0

SPECIMEN I.D.: A100-1
DRAWING NUMBER:
DATE: 07-07-89
MACHINE: 12
WAVEFORM: TRIANGULAR
R-RATIO: .8
A-RATIO: .1111111
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 1.9685
NOTCH LENGTH, mm: 1.143
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
212675	0.000	8.23	0.00	0.000	0.0	0.000E+00
225015	0.000	8.57	8.40	0.301	15.7	0.278E-07
228465	0.000	9.36	8.97	0.321	16.4	0.228E-06
230747	0.000	9.63	9.48	0.339	17.1	0.944E-07
233078	0.000	9.78	9.87	0.353	17.6	0.133E-06
235896	0.000	10.21	10.11	0.362	17.9	0.138E-06
240273	0.000	10.67	10.65	0.381	18.6	0.189E-06
242875	0.000	11.14	10.90	0.390	18.9	0.181E-06
245372	0.000	11.84	11.49	0.411	19.7	0.280E-06
247114	0.000	13.21	12.52	0.448	21.1	0.787E-06

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A100-1,200CPM,649C,R=.8

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): .033
MAX. LOAD, kg: 2245
MIN. LOAD, kg: 224.5
LOAD RANGE, kg: 2020.5
CYCLE OFFSET: 0

SPECIMEN I.D.: A99-6
DRAWING NUMBER:
DATE: 06-26-89
MACHINE: 6
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 2.0574
NOTCH LENGTH, mm: 1.27
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	0.00	0.00	0.000	0.0	0.000E+00

Crack growing vertically only; failed at 1060 cycles.

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): .033
MAX. LOAD, kg: 1570.909
MIN. LOAD, kg: 157.2727
LOAD RANGE, kg: 1413.636
CYCLE OFFSET: 0

SPECIMEN I.D.: A103-6
DRAWING NUMBER:
DATE: 07-07-89
MACHINE: 13
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 1.9939
NOTCH LENGTH, mm: 1.143
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	7.09	0.00	0.000	0.0	0.000E+00
100	0.000	7.20	7.14	0.256	46.2	0.114E-05
400	0.000	7.24	7.22	0.258	46.5	0.127E-06
740	0.000	7.33	7.31	0.262	46.9	0.511E-07
1050	0.000	7.37	7.32	0.262	47.0	0.449E-07
7842	0.000	7.52	7.59	0.272	48.1	0.448E-07
8050	0.000	7.61	7.60	0.272	48.1	0.431E-07
8410	0.000	7.70	7.62	0.273	48.2	0.427E-07
9840	0.000	7.72	7.71	0.276	48.5	0.178E-07
10780	0.000	7.76	7.74	0.277	48.7	0.405E-07
11020	0.000	7.79	7.77	0.278	48.8	0.106E-06

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

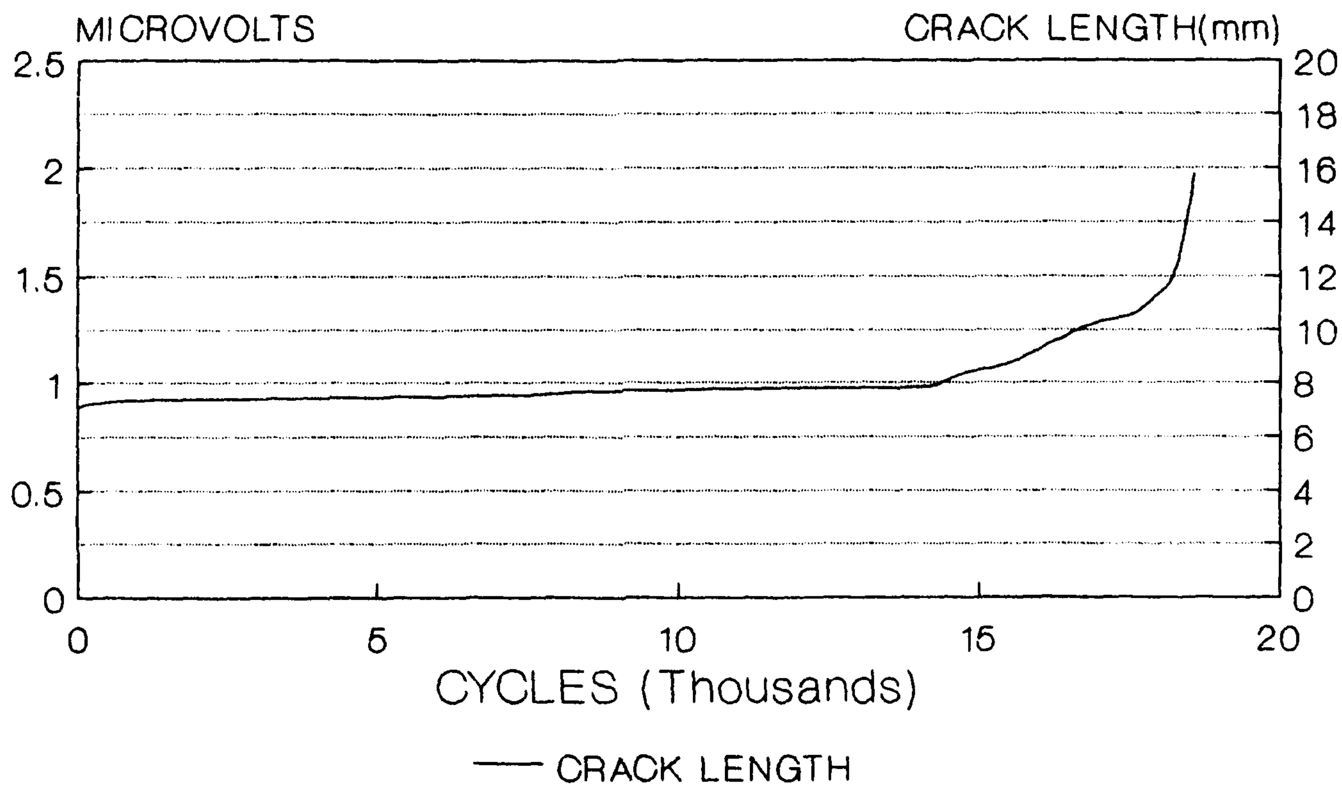
MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): .033
MAX. LOAD, kg: 1767.273
MIN. LOAD, kg: 176.8182
LOAD RANGE, kg: 1590.454
CYCLE OFFSET: 0

SPECIMEN I.D.: A103-6
DRAWING NUMBER:
DATE: 07-07-89
MACHINE: 13
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 1.9939
NOTCH LENGTH, mm: 1.143
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
13791	0.000	7.79	0.00	0.000	0.0	0.000E+00
14351	0.000	7.85	7.82	0.280	55.1	0.113E-06
14701	0.000	8.43	8.14	0.291	56.6	0.167E-05
15251	0.000	8.48	8.58	0.307	58.6	0.733E-06
15905	0.000	9.12	9.17	0.328	61.3	0.873E-06
16228	0.000	9.56	9.47	0.339	62.7	0.895E-06
16391	0.000	9.65	9.70	0.347	63.8	0.100E-05
16591	0.000	9.98	9.94	0.356	64.9	0.921E-06
16971	0.000	10.29	10.27	0.367	66.5	0.757E-06
17265	0.000	10.41	10.44	0.374	67.3	0.740E-06
17391	0.000	10.46	10.48	0.375	67.5	0.878E-06
17536	0.000	10.53	10.58	0.379	68.0	0.113E-05
17718	0.000	10.78	10.75	0.385	68.8	0.182E-05
17981	0.000	11.35	11.25	0.403	71.2	0.250E-05
18140	0.000	11.58	11.77	0.421	73.8	0.353E-05
18301	0.000	12.42	12.68	0.454	78.5	0.493E-05
18389	0.000	13.23	13.31	0.477	81.8	0.733E-05
18458	0.000	14.29	14.12	0.505	86.3	0.976E-05
18522	0.000	15.01	14.65	0.524	89.4	0.113E-04
18562	0.000	15.56	15.28	0.547	93.3	0.137E-04

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
18571	0.000	15.75	15.65	0.560	95.6	0.212E-04

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A103-6,2CPM,649C,R=.1

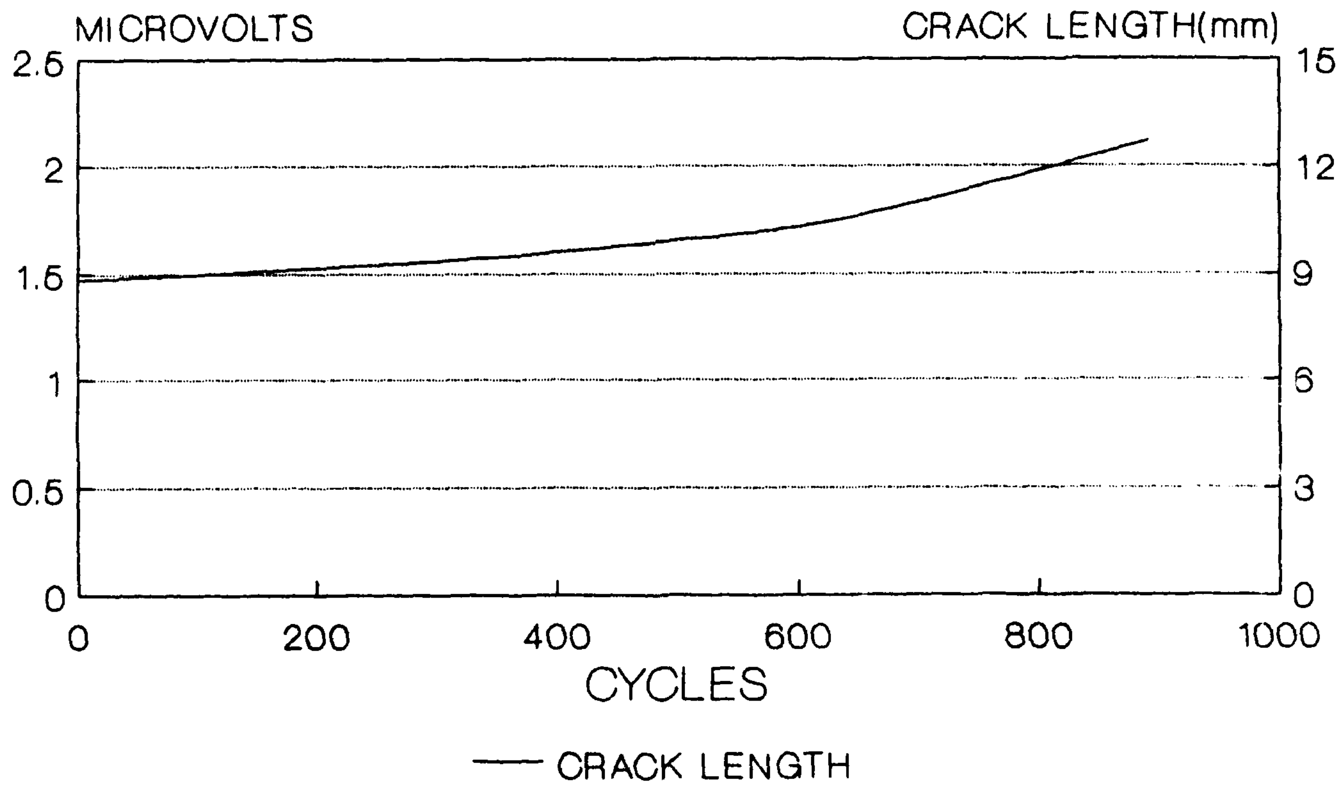
M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): .033
MAX. LOAD, kg: 1481.818
MIN. LOAD, kg: 148.1818
LOAD RANGE, kg: 1333.636
CYCLE OFFSET: 0

SPECIMEN I.D.: A105-1
DRAWING NUMBER:
DATE: 06-26-89
MACHINE: 3
WAVEFORM: TRIANGULAR
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 2.2606
NOTCH LENGTH, mm: 1.016
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	8.84	0.00	0.000	0.0	0.000E+00
330	0.000	9.31	9.07	0.325	45.0	0.142E-05
490	0.000	9.97	9.64	0.345	47.0	0.413E-05
630	0.000	10.22	10.10	0.361	48.6	0.181E-05
820	0.000	12.05	11.14	0.399	52.3	0.963E-05
890	0.000	12.70	12.38	0.443	56.9	0.925E-05

MBRC
PD DROP,A VS CYCLE



ALLISON,H838867,A105-1,2CPM,649C,R=.1

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): .0033
MAX. LOAD, kg: 2040.909
MIN. LOAD, kg: 204.0909
LOAD RANGE, kg: 1836.818
CYCLE OFFSET: 0

SPECIMEN I.D.: A102-1
DRAWING NUMBER:
DATE: 06-26-89
MACHINE: 3
WAVEFORM: DWELL
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 27.94
THICKNESS (B), mm: 2.0574
NOTCH LENGTH, mm: 1.1684
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

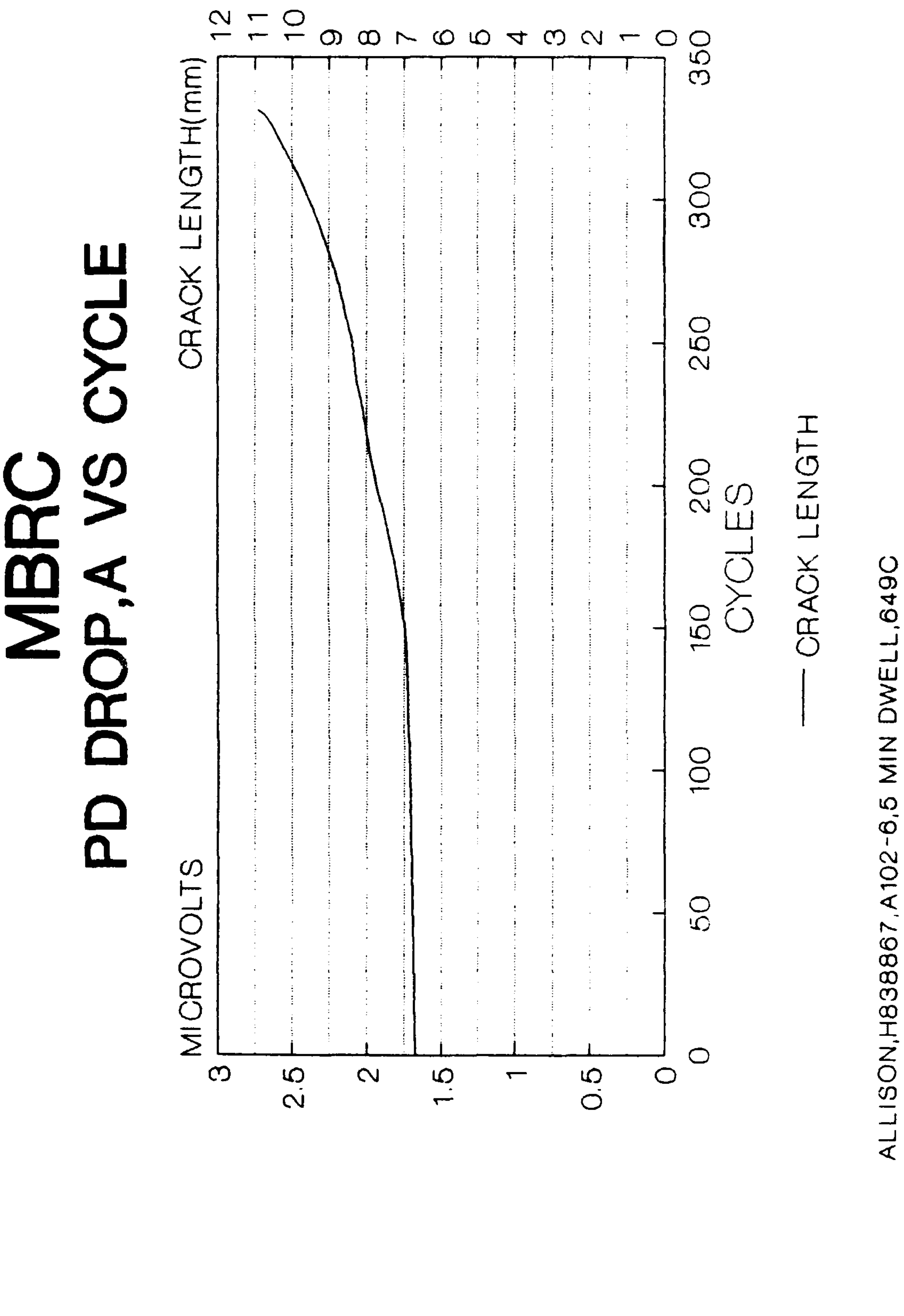
CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	4.67	0.00	0.000	0.0	0.000E+00
3	0.000	5.21	4.94	0.177	46.6	0.178E-03
12	0.000	5.31	5.26	0.188	48.4	0.113E-04
35	0.000	5.38	5.48	0.196	49.5	0.978E-05
43	0.000	5.50	5.52	0.197	49.7	0.732E-05
55	0.000	5.71	5.59	0.200	50.1	0.799E-05
83	0.000	5.75	5.81	0.208	51.3	0.905E-05
108	0.000	5.99	6.04	0.216	52.5	0.906E-05
120	0.000	6.22	6.15	0.220	53.1	0.122E-04
131	0.000	6.34	6.34	0.227	54.1	0.209E-04
139	0.000	6.40	6.37	0.228	54.2	0.794E-05
155	0.000	7.01	6.71	0.240	56.0	0.381E-04
163	0.000	7.62	7.32	0.262	59.1	0.762E-04

M.B.R.C. TEST REPORTING
CRACK GROWTH TESTING USING D.C. POTENTIAL DIFFERENCE TECHNIQUE

MBRC JOB: 010-092
CUSTOMER NAME: ALLISON
CONTACT: GAMBONE
PURCHASE ORDER: H838867
RELEASE:
MATERIAL I.D.: SCS-6/TI3AL LONG.
TEMPERATURE (C): 648.8889
FREQUENCY (Hz): .0033
MAX. LOAD, kg: 1483.636
MIN. LOAD, kg: 148.3636
LOAD RANGE, kg: 1335.273
CYCLE OFFSET: 0

SPECIMEN I.D.: A102-6
DRAWING NUMBER:
DATE: 06-26-89
MACHINE: 3
WAVEFORM: DWELL
R-RATIO: .1
A-RATIO: .8181818
WIDTH (W), mm: 25.4
THICKNESS (B), mm: 2.0574
NOTCH LENGTH, mm: 1.143
PROBE SPACING, mm: 0
SPECIMEN TYPE: SINGLE EDGE NOTCH

CYCLE	P.D. VOLT (MICROVOLT)	A p.d. (mm)	A reg. (mm)	A/W	DELTA K (MPa*M^.5)	dA/dN (M/CYCLE)
0	0.000	6.71	0.00	0.000	0.0	0.000E+00
70	0.000	6.79	6.75	0.266	45.5	0.127E-05
130	0.000	6.90	6.85	0.270	45.9	0.169E-05
160	0.000	6.99	7.18	0.283	47.3	0.614E-05
210	0.000	7.92	7.80	0.307	50.0	0.956E-05
220	0.000	8.03	7.98	0.314	50.8	0.137E-04
230	0.000	8.15	8.18	0.322	51.6	0.155E-04
240	0.000	8.33	8.28	0.326	52.1	0.132E-04
250	0.000	8.36	8.40	0.331	52.6	0.176E-04
260	0.000	8.60	8.54	0.336	53.2	0.229E-04
270	0.000	8.71	8.72	0.343	54.0	0.264E-04
300	0.000	9.47	9.51	0.375	57.5	0.299E-04
320	0.000	10.31	9.89	0.389	59.2	0.419E-04
330	0.000	10.68	10.50	0.413	62.0	0.368E-04
331	0.000	10.92	10.80	0.425	63.4	0.241E-03


MBRC
PD DROP,A VS CYCLE
MICROVOLTS
CRACK LENGTH(mm)
3
2.5
2
1.5
1
0.5
0
12
11
10
9
8
7
6
5
4
3
2
1
0
0
50
100
150
200
250
300
350
CYCLES
CRACK LENGTH
ALLISON,H838867,A102-6,5 MIN DWELL,649C

APPENDIX D

Task IV. Thermal Mechanical Fatigue Data

Material's Behavior Research Corporation

TABLE I

THERMAL-MECHANICAL LCF FINAL DATA SUMMARY: 05-26-89

STRAIN CONTROLLED TESTS

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-091
P.O. No.: H838854

STRAIN R-RATIO: .1
MIN TEMPERATURE, DEG.C: 93
MAX TEMPERATURE, DEG.C: 649
WAVEFORM: IN PHASE
FREQUENCY Hz: .0109

		MODULI,GPa				1st CYCLE			Ni/2 (Nf/2 if no Ni)				
		TEMPERATURE											
SPECIMEN ID	MACH	RT	MIN	MAX	STRN RNG%	STSS RNG MPa	MAX STSS MPa	MAX STRN %	STSS RNG MPa	MAX STSS MPa	Ni CYCLE	N5 CYCLE	Nf CYCLE
A074-01	6	178	177	155	0.650	706	836	0.874	560	332	705	-0	804
A074-05	6	200	197	174	0.600	537	711	0.680	773	544	705	705	775
A074-06	5	184	183	159	0.570	580	760	0.639	698	488	2920	-0	6218
A051-05	6	194	192	168	0.550	779	794	0.470	788	591	-0	9950	10040
A051-03	6	189	188	167	0.500	772	769	0.460	616	425	3800	2900	3830

ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

Ni = DEVIATION OF STRESS FROM TREND AT STEADY STATE WHICH RESULTS IN GROSS FAILURE
N5 = CYCLES TO 5% DECREASE IN STEADY STATE MAX STRESS
Nf = TOTAL TEST CYCLES OR CYCLES TO 50% DECREASE IN STEADY STATE MAX STRESS

A074-01 CRACK DESC.: OG;S;-0.50;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM 0.571% TO 0.874% ON CYCLE 1, & FROM 0.69% TO 0.742% ON CYCLE 5.

A074-05 CRACK DESC.: OG;S;+0.45;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM 0.425% TO 0.68% ON CYCLE 1.

A074-06 CRACK DESC.: OG;S;-0.45;MULTIPLE INITIATIONS;---;---;P
COMMENTS: LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM 0.43% TO 0.639% ON CYCLE 1 & FROM 0.62% TO 0.78% ON CYCLE 2.

A051-05 CRACK DESC.: UNLOADED IN ONE PIECE
COMMENTS: LONGITUDINAL. STOPPED TEST - RUNOUT AT 10040 CYCLES. SPECIMEN POPPED OUT IN STRAIN FROM 0.52% TO 0.735% ON CYCLE 3, FROM 0.50% TO 0.599% ON CYCLE 4, AND FROM 0.608% TO 0.955% ON CYCLE 5.

A051-03 CRACK DESC.: OG;S;+0.55;MULTIPLE INITIATIONS;---;---;P
COMMENTS: LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM 0.515% TO 0.77% ON CYCLE 2.

Material's Behavior Research Corporation

TABLE I

THERMAL-MECHANICAL LCF FINAL DATA SUMMARY: 05-26-89

STRAIN CONTROLLED TESTS

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-091
P.O. No.: H838854

STRAIN R-RATIO: .5
MIN TEMPERATURE, DEG.C: 93
MAX TEMPERATURE, DEG.C: 649
WAVEFORM: IN PHASE
FREQUENCY Hz: .0109

SPECIMEN ID	MACH	MODULI,GPa TEMPERATURE RT	MIN	MAX	STRN RNG%	1st CYCLE STSS RNG MPa	MAX STSS MPa	MAX STRN %	Ni/2 (Nf/2 if no Ni) STSS RNG MPa	MAX STSS MPa	Ni CYCLE	N5 CYCLE	Nf CYCLE
A059-01	6	170	162	144	0.500	404	1028	0.750	-0	-0	-0	-0	-0
A060-01	6	199	198	178	0.475	533	788	0.619	676	504	2950	-0	2955
A059-09	6	183	178	158	0.450	416	988	0.682	542	415	-0	8440	8850
A054-08	6	184	177	159	0.400	515	859	0.659	603	606	-0	-0	10022
A053-03	6	183	181	161	0.350	778	850	0.885	558	471	-0	5725	10026

ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

Ni = DEVIATION OF STRESS FROM TREND AT STEADY STATE WHICH RESULTS IN GROSS FAILURE
N5 = CYCLES TO 5% DECREASE IN STEADY STATE MAX STRESS
Nf = TOTAL TEST CYCLES OR CYCLES TO 50% DECREASE IN STEADY STATE MAX STRESS

A059-01 CRACK DESC.:
COMMENTS: LONGITUDINAL. SPECIMEN FAILED AT 0.89%, 1211.6 MPa BEFORE REACHING DESIRED MAX STRAIN OF 1.00%.

A060-01 CRACK DESC.: OG;I & S;MULTI.INITS. ON MULTI.PLANES;---;---;P+S
COMMENTS: LONGITUDINAL.

A059-09 CRACK DESC.: UNLOADED IN ONE PIECE
COMMENTS: LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM 0.541% TO 0.60% & AGAIN FROM 0.65% TO 1.022% ON CYCLE 2. STOPPED TEST - RUNOUT AT 8,850 CYCLES.

A054-08 CRACK DESC.: UNLOADED IN ONE PIECE
COMMENTS: LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM 0.531% TO 0.659% ON CYCLE 1 AND FROM 0.70% TO 0.942% ON CYCLE 2. STOPPED TEST - RUNOUT AT 10,002 CYCLES.

A053-03 CRACK DESC.: UNLOADED IN ONE PIECE
COMMENTS: LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM 0.525% TO 0.885% ON CYCLE 1. STOPPED TEST - RUNOUT AT 10,026 CYCLES.

Material's Behavior Research Corporation
TABLE I

THERMAL-MECHANICAL LCF FINAL DATA SUMMARY: 05-26-89

STRAIN CONTROLLED TESTS

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-091
P.O. No.: H838854

STRAIN R-RATIO: .1
MIN TEMPERATURE, DEG.C: 93
MAX TEMPERATURE, DEG.C: 649
WAVEFORM: 180 DEG. OUT OF PHASE
FREQUENCY Hz: .0109

SPECIMEN ID	MACH	MODULI, GPa TEMPERATURE RT	MIN	MAX	STRN RNG%	1st CYCLE STSS RNG MPa	MAX STSS MPa	MAX STRN %	Ni/2 (Nf/2 if no Ni) STSS RNG MPa	MAX STSS MPa	Ni CYCLE	N5 CYCLE	Nf CYCLE
A074-09	6	191	190	170	0.400	312	367	0.186	657	565	1280	-0	1441
A074-07	5	171	170	149	0.350	341	434	0.225	578	493	1091	1091	1395
A051-07	5	188	185	162	0.300	559	624	0.290	607	557	1660	1710	2204
A051-10	5	181	180	158	0.250	332	396	0.186	462	429	-0	-0	2241
A051-08	5	183	182	159	0.200	367	395	0.198	395	358	5178	7821	7821

ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

Ni = DEVIATION OF STRESS FROM TREND AT STEADY STATE WHICH RESULTS IN GROSS FAILURE
N5 = CYCLES TO 5% DECREASE IN STEADY STATE MAX STRESS
Nf = TOTAL TEST CYCLES OR CYCLES TO 50% DECREASE IN STEADY STATE MAX STRESS

A074-09 CRACK DESC.: OG;S;MULTI.INITS. ON MULTI.PLANES;---;---;P+S
COMMENTS: LONGITUDINAL.
A074-07 CRACK DESC.: OG;S;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM 0.338% TO 0.58% ON CYCLE 4.
A051-07 CRACK DESC.: OG;I & S;MULTI.INITS. ON MULTI.PLANES;---;---;P+S
COMMENTS: LONGITUDINAL.
A051-10 CRACK DESC.: OG;S;+0.55;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: LONGITUDINAL. DIGITAL DATA IS UNAVAILABLE DUE TO DISK ERROR; BASED ON LOOPS Ni OCCURRED SOMETIME AFTER CYCLE 2170.
A051-08 CRACK DESC.: OG;S;MULTI.INITS. ON MULTI.PLANES;---;---;P+S

Material's Behavior Research Corporation

TABLE I

THERMAL-MECHANICAL LCF FINAL DATA SUMMARY: 05-26-89

STRAIN CONTROLLED TESTS

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-091
P.O. No.: H838854

STRAIN R-RATIO: .1
MIN TEMPERATURE, DEG.C: 316
MAX TEMPERATURE, DEG.C: 649
WAVEFORM: IN PHASE
FREQUENCY Hz: .0109

SPECIMEN ID	MACH	MODULI,GPa TEMPERATURE RT	MIN	MAX	STRN RNG%	1st CYCLE STSS RNG MPa	MAX STSS MPa	MAX STRN %	Ni/2 (Nf/2 if no Ni) STSS RNG MPa	MAX STSS MPa	Ni CYCLE	N5 CYCLE	Nf CYCLE
A053-05	5	191	183	164	0.600	904	879	0.500	1066	933	381	368	478
A060-08	5	192	184	165	0.580	1019	975	0.572	1114	970	167	-0	167
A054-01	5	194	187	167	0.550	883	868	0.480	889	730	3038	-0	3038
A059-10	5	191	185	165	0.530	1000	952	0.559	834	692	955	767	1106
A053-09	5	189	181	163	0.500	896	879	0.494	736	596	-0	6355	10000

ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

Ni = DEVIATION OF STRESS FROM TREND AT STEADY STATE WHICH RESULTS IN GROSS FAILURE
N5 = CYCLES TO 5% DECREASE IN STEADY STATE MAX STRESS
Nf = TOTAL TEST CYCLES OR CYCLES TO 50% DECREASE IN STEADY STATE MAX STRESS

A053-05 CRACK DESC.: IG;S;MULTI. INITS. ON MULTI.PLANES;---;---;P+S
COMMENTS: LONGITUDINAL.
A060-08 CRACK DESC.: OG;S;MULTI.INITS. ON MULTI.PLANES;---;---;P+S
COMMENTS: LONGITUDINAL.
A054-01 CRACK DESC.: OG;S;+0.43;MULTIPLE INITIATIONS;---;---;P+S
COMMENTS: LONGITUDINAL.
A059-10 CRACK DESC.: IG;S;+0.43;---;0.00;0.08;P+S
COMMENTS: LONGITUDINAL. ONE HALF OF SPECIMEN MELTED AFTER FAILURE.
A053-09 CRACK DESC.: UNLOADED IN ONE PIECE
COMMENTS: LONGITUDINAL. STOPPED TEST - RUNOUT AT 10,000 CYCLES.

Material's Behavior Research Corporation
TABLE I

THERMAL-MECHANICAL LCF FINAL DATA SUMMARY: 05-26-89

STRAIN CONTROLLED TESTS

Ti3AL/SCS-6 ALLOY

AGT Engineer: GAMBONE
Vendor phone:(513)248-1722
MBRC Job No.: 010-091
P.O. No.: H838854

STRAIN R-RATIO: .1
MIN TEMPERATURE, DEG.C: 316
MAX TEMPERATURE, DEG.C: 649
WAVEFORM: 180 DEG. OUT OF PHASE
FREQUENCY Hz: .0109

SPECIMEN ID	MACH	MODULI, GPa TEMPERATURE RT	MIN	MAX	STRN RNG%	1st CYCLE STSS RNG MPa	MAX STSS MPa	MAX STRN %	Ni/2 (Nf/2 if no Ni) STSS RNG MPa	MAX STSS MPa	Ni CYCLE	N5 CYCLE	Nf CYCLE
A054-02	5	191	184	163	0.550	831	850	0.437	893	798	610	-0	664
A053-06	5	192	185	166	0.500	958	829	0.508	844	698	1621	-0	1621
A059-04	6	183	175	156	0.450	657	670	0.372	689	568	1880	2060	3080
A060-02	6	189	179	161	0.400	591	633	0.332	577	498	3480	3440	4400
A060-07	5	194	186	166	0.350	519	574	0.270	677	679	997	900	997

ABOVE, 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'.

Ni = DEVIATION OF STRESS FROM TREND AT STEADY STATE WHICH RESULTS IN GROSS FAILURE
N5 = CYCLES TO 5% DECREASE IN STEADY STATE MAX STRESS
Nf = TOTAL TEST CYCLES OR CYCLES TO 50% DECREASE IN STEADY STATE MAX STRESS

A054-02 CRACK DESC.: IG;S;MULTI.INITS. ON MULTI.PLANES;---;---;P+S
COMMENTS: LONGITUDINAL. SPECIMEN BELIEVED TO HAVE POPPED OUT IN STRAIN AT CYCLES 91 AND 142. SHARP DROP IN LOAD AT THESE CYCLES CAUSED MACHINE TO SHUT DOWN, THEREFORE DIGITAL DATA IS NOT AVAILABLE TO DETERMINE ACTUAL STRAIN PRECEEDING DROP IN LOAD.

A053-06 CRACK DESC.: OG;S;MULTI.INITS. ON MULTI.PLANES;---;---;P+S
COMMENTS: LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM 0.43% TO 0.508% ON CYCLE 1 AND FROM 0.541% TO 0.60% ON CYCLE 2. AS A RESULT, TEST WAS RUN AT 0.50% STRAIN RANGE INSTEAD OF 0.40%.

A059-04 CRACK DESC.: IG;S;-0.02;MULTIPLE INITIATIONS;---;---;P
COMMENTS: LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN FROM 0.454% TO 0.738% ON CYCLE 2.

A060-02	CRACK DESC.:	IG;S;+0.12;---;0.00;0.19;P+S
	COMMENTS:	LONGITUDINAL. SPECIMEN POPPED OUT IN STRAIN TO 0.64% AT CYCLE 68 AND TO 0.71% AT CYCLE 392.
A060-07	CRACK DESC.:	OG;S;+0.45;MULTIPLE INITIATIONS;---;---;P
	COMMENTS:	LONGITUDINAL

TASK VI TMF DATA

Material's Behavior Research Corporation

TMLCF DATA OBTAINED FOR SiC/Ti3AL ALLOY

USING AXIAL STRAIN MEASUREMENT AND CONTROL

FINAL DATA SUMMARY

06-16-88

MBRC JOB 010-082
CUSTOMER ALLISON
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RELEASE

****NOTE BELOW. A 'NEGATIVE ZERO' DENOTES 'NOT AVAILABLE' OR 'NOT APPLICABLE'. ****

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                                         ELASTIC               THERMAL
                                         MODULUS               EXP.     NOMINAL
                  ROOM   ROOM   TEST     X10(6) PSI            COEFF.   TENSILE    STRAIN CONTROL     LOAD CONTROL
                  TEMP   TEMP   TEMP     ----------    TEST    X10(-6)  FRACTURE   --------------     --------------                      RUN
SPECIMEN  MACH    DIAM.  AREA   AREA     ROOM   TEST   TEMP.   IN/IN/   STRESS              FREQ.              FREQ.     Ni         FINAL  TIME
   NO      NO     IN.    IN SQ  IN SQ.   TEMP.  TEMP.  DEG F   DEG F    KSI        CYCLES   CPS.     CYCLES    CPS.      CYCLE      CYCLE  HOURS
*****************************************************************************************************************************************************
                              NEAR START                                     AT HALF LIFE                               AT INITIAL CRACK
                  -----------------------------------      ------------------------------------------   ------------------------------------------
STRAIN      PSEUDO STRESS   MAX     MIN     ELAS.   PLAS.    STRESS   MAX     MIN      ELAS.   PLAS.   STRESS   MAX     MIN      ELAS.   PLAS
RANGE    A  STRESS RANGE    STRESS  STRESS  STRAIN  STRAIN   RANGE    STRESS  STRESS   STRAIN  STRAIN  RANGE    STRESS  STRESS   STRAIN  STRAIN
  %   RATIO KSI    KSI      KSI     KSI     %       %        KSI      KSI     KSI      %       %       KSI      KSI     KSI      %       %
*****************************************************************************************************************************************************
16L-12       7 -.0000  0.0237 0.0239 23.90 20.90  600       6.80  100.565       290   0.01          -0  -0.00      290        290   6.77
0.500 .82    -0.00 127.163 124.477    -2.686 -.000 -.000   119.843 115.690    -4.153 -.000 -.000  108.755 100.565   -8.190 -.000 -.000
16L-12 CRACK DESCRIPTION   OG.S.-0.27;MULTI. INITS.;P    WAVEFORM: TRIANG.;THERM./MECH 180DEG. OUT OF PHASE
16L-12 COMMENTS:  LONGITUDINAL. RT WIDTH = .3025"; RT THICKNESS = .0785".  AREA @1400 DEG.F. = 0.0242"; MODULUS @1400 DEG.F. =
18.7E6. ~300 THERMAL CYCLES PRIOR TO TEST.

16L-20       7 -.0000  0.0226 0.0228 25.50 23.80  600       6.80   -0.000       381   0.01          -0  -0.00      122        381   0.65
0.400 .82    -0.00 107.891 107.456    -0.435 -.000 -.000   105.021 102.412    -2.609 -.000 -.000  102.168  99.342   -2.826 -.000 -.000
16L-20 CRACK DESCRIPTION   OG.S.@R U S I.;MULTIPLE INITS.P+S    WAVEFORM. TRIANG.;THERM./MECH 180DEG. OUT OF PHASE
16L-20 COMMENTS   LONGITUDINAL. RT WIDTH = .2965", RT THICKNESS = .0762".  AREA @ 1400 DEG.F.= 0230". MODULUS @ 1400
DEG.F =21.8E6. 100 THERMAL CYCLES PRIOR TO START OF TEST. CRACKING ALONG UNIFORM SECTION  NOMINAL TENSILE FRACTURE STRESS N/A DUE
TO DISK ERROR.

16L-22       7 -.0000  0.0227 0.0228 24.90 22.90  600       6.80   -0.000      1048   0.01          -0  -0.00      483       1048  23.19
0.300 .83    -0.00  84.868  84.868     0.000 -.000 -.000    75.128  68.202    -6.926 -.000 -.000   70.210  62.846   -7.364 -.000 -.000
16L-22 CRACK DESCRIPTION   OG.S;MULTI INITS.,P+S    WAVEFORM. TRIANG.,THERM./MECH 180DEG  OUT OF PHASE
16L-22 COMMENTS   LONGITUDINAL  RT WIDTH = .3022", RT THICKNESS = .0750".  AREA @1400 DEG F. = 0.0231". MODULUS @1400 DEG F. =
21.1E6  ~215 THERMAL CYCLES PRIOR TO TEST  Ni BASED ON APPEARANCE OF HYSTERESIS LOOPS

16L-04       7 -.0000  0.0228 0.0229 24.00 21.10  600       6.80   52.738      2011   0.01          -0  -0.00     1960       2011  47.34
0.200 .83    -0.00  53.061  52.738    -0.323 -.000 -.000    47.275  45.271    -2.004 -.000 -.000   43.488  45.061    1.573 -.000 -.000
16L-04 CRACK DESCRIPTION:  OG.S;+0.55,MULTI. INITS.,P+S    WAVEFORM: TRIANG.;THERM./MECH 180DEG. OUT OF PHASE
16L-04 COMMENTS:  LONGITUDINAL. RT WIDTH = .2958", RT THICKNESS = .0770"  AREA @1400 DEG.F. = 0.0232", MODULUS @1400 DEG.F =
19.1E6. ~200 THERMAL CYCLES PRIOR TO TEST.
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16L-15      5 -.0000  0 0229 0 0230 26 70 24.80   600      6.80    8.317    3901   0.01      -0  -0.00    3650     3901  91.06
0 150  82   -0.00  45.884  46 957    1.073 -.000 -.000    35.574  19.565  -16.009 -.000 -.000   23 482   8.104  -15.378 -.000 -.000
'16L-15 CRACK DESCRIPTION  OG;S;+0.37;MULTI  INITS ;P+S   WAVEFORM  TRIANG.,THERM /MECH 180DEG  OUT OF PHASE
'16L-15 COMMENTS   LONGITUDINAL  RT WIDTH = .3007"; RT THICKNESS = .0760"   AREA @ 1400 DEG F = 0233", MODULUS @ 1400
'DEG F =22 8E6. 200 THERMAL CYCLES PRIOR TO START OF TEST

33-07       7 -.0000  0 0219 0.0220 21.20 19 30   600      6.80   16.577     623   0.01      -0  -0.00     210      623  14.54
0 250  81   -0.00  50.142  50.773    0 631 -.000 -.000    46.550  42.559   -3.991 -.000 -.000   40.763  35.673  -5.090 -.000 -.000
'33-07 CRACK DESCRIPTION  OG,S,@R.U.S.I.;MULTI.INITS.;P   WAVEFORM  TRIANG.,THERM./MECH 180DEG. OUT OF PHASE
'33-07 COMMENTS  0 DEC./90 DEG  CROSSPLY. RT WIDTH = .3025", RT THICKNESS = .0723".  AREA @1400 DEG.F. = 0.0222"; MODULUS @1400
'DEG.F. = 15.8E6. ~200 THERMAL CYCLES PRIOR TO TEST. CRACKING ALONG UNIFORM SECTION.

32-08       7 -.0000  0.0215 0.0217 22.00 19.70   600      6.80   12.544    1076   0.01      -0  -0.00     970     1076  25 12
0.200  83   -0.00  43 485  39.106   -4.379 -.000 -.000    31.747  23.797   -7 950 -.000 -.000   24.095  16.369  -7.726 -.000 -.000
'32-08 CRACK DESCRIPTION.  OG;S,@R.U.S.I.,MULTI.INITS.;P   WAVEFORM. TRIANG.;THERM./MECH 180DEG. OUT OF PHASE
'32-08 COMMENTS:  0 DEG /90 DEG. CROSSPLY. RT WIDTH = .3033"; RT THICKNESS = .0710".  AREA @1400 DEG.F. = 0.0219", MODULUS @1400
'DEG.F. = 15.5E6. ~150 THERMAL CYCLES PRIOR TO TEST

32-07       7 -.0000  0.0214 0.0216 22.00 19.70   600      6.80   15.940    2128   0.01      -0  -0.00     490     2128  49.67
0.150  82   -0.00  34.259  31.319   -2.940 -.000 -.000    30.420  27.704   -2.716 -.000 -.000   28.139  23.630  -4.509 -.000 -.000
'32-07 CRACK DESCRIPTION:  OG;S;MULTI.INITS. ON MULTI. PLANES;P+S   WAVEFORM: TRIANG.;THERM./MECH 180DEG. OUT OF PHASE
'32-07 COMMENTS.  0 DEC./90 DEG. CROSSPLY. RT WIDTH = 0.3027"; RT THICKNESS = 0.0708". AREA @1400 DEG.F. = 0.0218", MODULUS @1400
'DEG.F. = 16.0E6. ~100 THERMAL CYCLES  PRIOR TO TEST. CRACKING ALONG UNIFORM SECTION.

35-08       7 -.0000  0.0239 0.0241 23.20 21.10   600      6.80   12.834     845   0.01      -0  -0.00      75      845  19.72
0.200  83   -0.00  40.672  35.942   -4.730 -.000 -.000    38.652  34.320   -4.332 -.000 -.000   37.424  32.494  -4.930 -.000 -.000
'35-08 CRACK DESCRIPTION:  OG;S;+0.64;MULTI. INITS.;P+S   WAVEFORM. TRIANG.;THERM./MECH 180DEG. OUT OF PHASE
'35-08 COMMENTS:  0 DEG./P/M 45 DEG./90 DEG. CROSSPLY. RT WIDTH = .2962"; RT THICKNESS = .0808".  AREA @1400 DEG.F. = 0.0244";
'MODULUS @1400 DEG.F. = 17.2E6. ~200 THERMAL CYCLES. Ni BASED ON APPEARANCE OF HYSTERESIS LOOPS.

35-10       7 -.0000  0.0244 0.0246 18.90 17.40   600      6.80   11.541    1349   0.01      -0  -0.00     350     1349  30.97
0.200  83   -0.00  34.976  31.996   -2.980 -.000 -.000    30.541  25.244   -5.297 -.000 -.000   26.971  22.264  -4.707 -.000 -.000
'35-10 CRACK DESCRIPTION.  OG,S,-0.50,MULTIPLE INITIATIONS   WAVEFORM: TRIANG.;THERM./MECH 180DEG. OUT OF PHASE
'35-10 COMMENTS  0 DEG./P/M 45 DEG./90 DEG. CROSSPLY. RT WIDTH = 0.2986", RT THICKNESS = 0.0818". AREA @1400 DEG.F. = 0.0249".
'MODULUS @1400 DEG.F. = 12.6E6. ~80 THERMAL  CYCLES PRIOR TO TEST. Ni BASED ON APPEARANCE OF HYSTERESIS LOOPS. CRACKING ALONG
'UNIFORM SECTION.

45-02       7 -.0000  0.0220 0.0222 18.90 16.30   600      6.80    8.225    4646   0.01      -0  -0.00     690     4646 106.46
0.150  82   -0.00  28.559  25.613   -2.946 -.000 -.000    22.794  15.486   -7.308 -.000 -.000   21.252  13.288  -7 964 -.000 -.000
'45-02 CRACK DESCRIPTION.  OG;S,MULTI. INITS. ON MULTI. PLANES,P+S   WAVEFORM  TRIANG.;THERM./MECH 180DEG. OUT OF PHASE
'45-02 COMMENTS   O DEG./P/M 45 DEG./90 DEG. CROSSPLY  RT WIDTH = .2926"; RT THICKNESS = .0752".  AREA @1400 DEG.F = 0.0224".
'MODULUS @1400 DEG.F = 12 6E6. ~170 THERMAL CYCLES PRIOR TO TEST.
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27L-07      7 -.0000  0 0218 0 0219 25 50 23 40   200      6 80   -0 000    5144   0 01      -0  -0 00    3260     5144 131 09
0 200  83   -0 00  64 807  62 397   -2 410 -.000 -.000    51.646  49 457   -2 189 -.000 -.000   51 215  49 904  -1 311 -.000 -.000
'27L-07 CRACK DESCRIPTION   UNLOADED IN ONE PIECE   WAVEFORM  TRIANG .THERM /MECH 180DEG  OUT OF PHASE
'27L-07 COMMENTS   LONGITUDINAL  RT WIDTH = 0 2970", RT THICKNESS = 0 0735"  AREA @1200 DEG F  = 0 0222", MODULUS @1200 DEG F  =
'21 0E6  ~150 THERMAL CYCLES PRIOR TO TEST   STOPPED TEST - RUNOUT AT 5144 CYCLES
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